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Improving Learning Outcomes In EE2010l Using NI MYDAQ in an Inverted Lab

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IMPROVING LEARNING OUTCOMES IN EE2010L USING NI MYDAQ IN AN INVERTED LAB

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Doctor of Philosophy

By

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I HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER MY SUPERVISION BY Ryan Frederick Allen Hamilton ENTITLED Improving Learning Outcomes in EE2010L using NI MyDAQ in an Inverted Lab BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Doctor of Philosophy.

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Abstract

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EE 2010L Circuit Analysis Lab is an introductory course in analog circuits for students majoring in Electrical Engineering, Engineering Physics, Mechanical Engineering, Materials Science, and Computer Engineering at Wright State University. Prior to conversion to the semester calendar, from the quarter calendar, the course was known as EE 302 Circuit Analysis I Lab. In the terms since the semester conversion it has been noticed the percentage of students receiving grades of D (poor), F (failed), W (withdrawn), K (withdrawal in first two weeks), or X (unofficial withdrawal) has increased from the rate in the previous iteration of the course.

A new lab pedagogical method was developed for teaching the course. The new method made use of an inverted lab structure. Students were issued a myDAQ device made by National Instrument. When connected to a computer, the myDAQ can act as a power supply, multimeter, oscilloscope, and frequency generator. The myDAQ allows students to collect data outside of the lab. It is expected that students using the myDAQ will show the same learning outcomes as students in the traditional bench labs. It was hoped that by introducing this new instructional method can serve as a bridge to introducing more elements of problem based learning into the course.

A study was conducted during the Spring Semester of 2014 in order to test the effectiveness of the new instructional method. Half of the section of EE 2010L used

traditional equipment (bench labs) in a traditional lab setting. Students in this cohort collected data in the lab. The other half of the course sections used the new pedagogical method (myDAQ labs). Students in this cohort collected their data outside of class time. All students completed the same lab activities, same lab practicum midterm, and lab practicum final. Additionally, all students took the same pre- and post-test.

The results from the lab practica and the Hake's gain from the pre-test and post-test scores were treated as dependent variables. Student GPA, Major, Lab Type (bench or myDAQ), and assigned Teaching Assistant were used as the independent variables. MANOVA and MANCOVA analyses were performed on the data. The results of these analyses, along with additional post hoc testing, showed that only GPA was statistically significant upon the dependent variable measures.

The new instructional method was just as effective as the traditional method. These results mean that more elements of problem based learning may be introduced into the future curriculum for EE 2010L.

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1 Introduction

1.1 Background

At the beginning of the 2012-2013 academic year numerous public universities in Ohio modified the academic calendar from to quarter based to semesters based (Sullivan 2013). Prior each year had consisted of three quarters with 10 weeks of instruction and a finals week, after the conversion there were 14 weeks of instruction and a final week in each term. The conversion of Wright State University from a quarter based schedule to a semester based schedule in the Fall Semester of 2012 necessitated the redesign of virtually every course. This also provided a unique opportunity to study and evaluate how well each course is serving the students. In particular, it allowed for the study of large introductory courses which are the foundations for further advanced courses. Regrettably these courses often have high numbers of students receiving low grades. One such large introductory course is EE 2010L Circuit Analysis Lab, which is the focus of this dissertation. Among the aspects of the course which can be considered are ways to improve student learning outcomes, how the course's instruction is structured, and the effective management of resources needed for the course.

EE 2010L Circuit Analysis Lab is the required laboratory course to accompany EE 2010 Circuit Analysis. The course is required for students pursuing undergraduate degrees in Electrical Engineering, Engineering Physics, Mechanical Engineering, Computer Engineering, and Materials Sciences at Wright State University. It is the first course in analog electric circuits for students majoring in Electrical Engineering, Computer Engineering, and Engineering Physics. As such it is the foundation for all future analog electronics courses. It is the sole course in analog electric circuits for students majoring in Mechanical Engineering and Materials Science. EE 2010L provides the opportunity for students to see the theoretical material in practice, while they receive training in laboratory test equipment and its usage.

During the time frame under consideration in this study, the prerequisite for entry to the course was completion with a C or better in EGR 1010 Math for Engineering Applications or MTH 2300 Calculus I. Thus, students would not necessarily have taken any courses covering basic circuit theory. However, students in the course are a very diverse group, and there is a wide array of experiences with circuit theory. Some students have an extensive exposure to circuit theory through prior military or technical school experience. Other students have not had any prior exposure to even the most basic circuit theory ideas.

EE 2010L Circuit Analysis Lab is primarily focused on using the basic lab tools. Among the tools used are a digital multimeter to measure current, voltage, and resistance. Further, students make use of a DC power supply, a frequency generator as an AC power supply, and an oscilloscope. Since the conversion to semesters, the laboratory activities in which EE 2010L students use this equipment have covered the following topics:

- Resistors in Series & Parallel
- Combination Resistive Circuits
- Node Voltage & Mesh Current
- Thevenin & Norton equivalent Circuits
- Voltage & Current Divider Circuits
- Circuits containing networks of Resistors, Inductors, and/or Capacitors

1.2 Observations and Challenges

The first few terms on the semester system produced rather unexpected grade distributions in EE 2010L. The combined percentage of students receiving grades of A, B, or C in the lab declined when compared to percentage of students receiving such grades on the quarter system in EE 302 Circuit Analysis I Lab. In order to remain in good academic standing as a student at Wright State University, students must maintain a 2.0 GPA. This is a C average so grades of C and above will be considered successful completion of the course.

EE 2010L F12-F13		
Count		Percent
226	A	52.19
90	B	20.79
34	C	7.85
16	D	3.70
25	F	5.77
23	W	5.31
7	X	1.62
0	N	0.00
12	K	2.77
433	Total	100

EE 302 F07-R12		
Count		Percent
752	A	72.87
163	B	15.79
34	C	3.29
13	D	1.26
20	F	1.94
29	W	2.81
2	X	0.19
2	N	0.19
17	K	1.65
1032	Total	100

Table 1.2.1 Grade Distribution for EE 2010L and EE 302 Non-Repeating Students

As Table 1.2.1 shows the total number of students, and the percentage of all students who registered for the class which recieved each grade in the course. The right side of the table is the aggregate data of 20 quarter offerings of EE 302 and the left side is the aggregate of 4 semester offerings of EE 2010L. Grades appearing in the table which may be unique to Wright State University include X (unofficial withdrawal), N (no grade reported), and K (Withdrawal between second and fifth week). The N and K grades do not count toward a student's GPA. The X grade is awarded zero quality points and is factored into the GPA calculations. Twenty quarters worth of data is used in order to provide a solid based of the historical course outcomes. The additional data is included in order to provide a more accurate pattern of grade distributions produced that are not affected greatly by one term of very good or very bad grades. The final offering of EE 302 occurred in Summer Semester 2012 and the first offering of EE 2010L occurred in Fall Semester 2012.

One element that is readily apparent from the table is the percentage of students who do not successfully complete the class (F, X, or W grades) on semesters is 2.5 times what it was on quarters, 12.7% versus 4.9%. When we look at the total number of grades in the F, X, and W range there is a noticeable difference. More students in EE 2010L received a grade of F or X (32) than did students in EE 302 in the time frame considered (22). There were more failures even though there were far fewer students, 433 compared to 1032. Similarly, there were more D grades (16) in the four semesters of EE 2010L than there were in EE 302 (13) in the 20 previous quarters. While the percentages of lower grades are small now, it is important to correct the problem before it becomes larger. The goal of this dissertation is to improve student learning through use of an inverted lab structure while maintaining the academic rigor of the course. EE 2010L is an important class as it acts as a “gateway” course. Before they can proceed to more advanced courses in their field students need to successfully pass the courses. Students who are unsuccessful in the course often find themselves delayed in degree progress by a semester.

EE 2010L replaced EE 302. There are several changes that occurred which may have impacted the grade distribution. Among these changes was the conversion from the quarter schedule to semester schedule. With the semester switch, a follow up course to

EE 302 was dropped, which pushed more material into EE 2010L. This has led to a time crunch in attempting to teach what was covered in 20 weeks in just 14 weeks. Trying to cover more material at a quicker pace has also taxed the lab instructors (the TAs actually in the lab). The TA now has more students in the same amount of time to interact with students, this leads to a decrease in the amount of time the TA can spend with any student. Further, there was a change in prerequisites designed to get students into the course sooner. A physics course covering basic electromagnetic theory was dropped as a prerequisite. Changes are underway which will likely result in the reintroduction of the physics prerequisite in order to help improve student outcomes. Additionally, there has been a shift in the college admission policy which allows any student admitted to Wright State University to begin in the College of Engineering and Computer Science immediately. Previously, students with a marginal academic history began in University College. The shift in admissions has increased the number of students who make it to fundamental engineering courses such as EE 2010 and EE 2010L. All these factors ultimately contributed to an expansion in class size of EE 2010L and greatly increased the diversity of student preparation when they enter the course. On quarters, it was not uncommon to have lab sections with 16 or fewer students. On the semester schedule the average class has 20 students. Many lab sections have 22 students. This increase in class size and variance of students' prior experience put a great deal of stress on the teaching resources for the course. These changes have produced challenges for maintaining academic rigor while providing a positive learning experience for students.

1.3 Motivation

The above changes have negatively impacted the percentage grade distribution for the course. A more effective use of course resources is important for improving student learning outcomes. The inverted lab structure used in this dissertation provides several opportunities for better allocation of resources. In a traditional lab the students only have a finite length of time with the equipment. The inverted structure makes use of National Instruments myDAQ device. This is a USB connected device which allows a student to use virtual test equipment while still manipulating physical circuits. Using myDAQs students can complete measurements outside of designated class time. Removing the restraint of a fixed length of time with the equipment also allows for better allocation of teaching resources. TAs for the inverted sections, have additional open lab time throughout the week, in addition to class time. This provides the student with more opportunities to interact and get questions answered as needed. The inverted lab meets for roughly half the time as a typical lab. The open lab time for a TA is no additional burden to them, and no additional cost to the department. All of which, it is hoped, will improve student learning outcomes and success in an early degree course.

Students are entering the course sooner, facing larger class sizes, and getting less time with the lab equipment. When students fail in such an early foundational course we are likely to lose them as engineers. French et al. (2005) found that student attrition in engineering is often directly linked to their feelings toward engineering. A major component of a student's positive attitude toward engineering is their academic performance. Another important factor is their interest in the methods of instruction.

This dissertation is an attempt to overcome those hurdles and improve the student experience by demonstrating the following outcomes. The less success students have in early classes, the less likely they are to persist in their chosen major (French et al., 2005). It was hoped that the introduction of the myDAQs would improve student learning and retention. Previous work at Texas Tech University by Chestnutt and Baker (2011) and University of Texas by Chun and McCann (2011) hint at improvements in student learning outcomes using myDAQs in a basic circuit theory course. These studies are limited in scope and often only discuss the types of lab activities created and the authors' perceived improvement in the course (Yao et. al. 2010 and Sharad and Robbins, 2010). Yao et al. (2010) focused on the instructors perceived improvements to the course, and were just beginning to develop measurement instruments to determine how well the students had mastered the material. They did not collect data for courses taught using the traditional methods with which to compare. Chestnutt and Baker (2011) again rely on the instructors perceived improvements and did not provide statically data for comparison. Chun and McCann (2011) collected data but it was based on student opinion. They asked students questions about how they felt the myDAQ impacted the course and did not measure learning outcomes. It also does not offer comparisons to prior term's learning outcomes using traditional methods. This dissertation will demonstrate statistical measures of learning outcomes for comparison between the two methods of instruction.

These studies focus on improvement. However, there also exist among some faculty the opinion that a change to virtual instrumentation would have a negative impact upon student learning outcomes. Those of this opinion believe that by removing the physical instruments, such as power supplies, multimeters, oscilloscopes, and frequency generators, students will be less prepared to move on in the curriculum and will not be able to export the skills learned when using the myDAQ to physical instrumentation. This dissertation seeks to prove that there is no difference and students will be able to export their skills to physical instrumentation.

All data in this dissertation covering EE 2010L comes from one term, using control and test groups in quasi experimental design. This dissertation is an attempt to address the gap and provide verifiable empirical data showing improved student learning. It is hoped that increasing students' basic understanding of a core subject will increase their persistence in the degree. This dissertation is an attempt to improve student success in an early foundational course.

It is also desired to move the lab activities for the course from traditional closed-ended lab activities to more open-ended project-based activities. Close-ended lab activities are those in which the answer can be calculated empirically and all students will be expected to have very similar data. Typically these activities have only one correct way to solve the task at hand. Open-ended lab activities, by contrast, often do not have one definitive answer. There also exists a multitude of ways in which to obtain the answer.

The myDAQ is more amenable to use with project-based labs. This study aims to determine if the myDAQ is as effective as bench labs for student learning outcomes and if it can be used to introduce more elements of problem-based learning into the EE 2010L curriculum. Such a switch would require different lab equipment. This dissertation will serve as an intermediate step to determine whether or not the new method is as effective as, or more effective than, or even possibly less effective than the traditional instructional method.

1.4 Objective

Prior studies, such as those of Baker and Chestnutt (2011) and Yao et al. (2010), indicate that students perform better using the myDAQ devices than using standard bench lab equipment. Based on these, the expected results of this dissertation are the following. Among the faculty at Wright State University, there are some who also feel the switch to myDAQs in an inverted lab structure would have a negative impact on student learning. This dissertation seeks to show that there will be no difference between the learning outcomes of students using the myDAQ in the inverted lab and students in the traditional lab. The treatment will not have a negative impact upon the student learning outcomes. The inverted labs will be more cost effective and more time effective. It is further expected that students who use the myDAQ will spend more time with the lab activities because they will have individual equipment. As a result, it is believed that since the two instructional methods will prove to be equivalent, the cost and time benefits will allow for a change to the curriculum of EE 2010L. The new curriculum could be used to introduce more project based activities as opposed to the current closed-ended lab activities in use with the course.

This study was a systematic attempt to improve the instruction of EE 2010L Circuit Analysis I. A new instructional method was developed to try to improve student learning outcomes. It is expected that as a result of the new pedagogical method, students will perform better at measuring current, voltage, and resistance in basic analog circuits containing resistors, capacitors, and inductors with both DC and AC signals. These students will also have a better understanding of the current and voltage relationship for resistors in series and resistors in parallel.

Improving the allocation of resources is important to improving student success. Leveraging new technology will be an important part of changing the instructional method. Dani & Koenig (2008) have stated that the use of technology can be an important component to innovative teaching methods to improve students' scientific literacy. The new instructional method will make use of the National Instrument myDAQ. This is a small personal data acquisition system. The myDAQ comes with software which functions the same as a typical multimeter, DC power supply, frequency generator, and oscilloscope. A direct comparison will be made between students taught with the typical method and students taught with the new instructional method. The analysis and design of this new instructional method will employ concepts and ideas from the well established field of Discipline Based Educational Research (DBER).

The new instructional method will also introduce the course experience more customizable to the individual student. Students will be able to determine when and where they collect data. Students will have the ability to collect all the data in one sitting or multiple sittings. They can also choose where they will collect their data, at home, in the library, in a study lounge, alone, or with classmates. They can also adjust the amount of interaction with course instructors. Student can limit interaction to just class time, or they can use class time and open lab time. Similarly, students may attend open lab time from several different TAs. Students may find a TA who can explain material in a way which better fits that's student learning style. Students can tailor the lab experience to their own learning style in the new inverted lab structure. Everyone will have the same learning outcomes, but students will have the opportunity to mold the course experience in such a way as to maximize their ability to meet them.

As part of the course conversion from quarters to semesters a set of course learning outcomes were established. The outcomes state what major concepts students should master in order to successfully complete the course. The stated learning outcomes of EE 2010L Circuit Analysis lab are:

1.) The ability to apply Kirchhoff's laws to DC circuits (node-voltage techniques)

Kirchhoff's laws require validation. This validation comes from direct measurement of current and voltage. As will be discussed later, the myDAQ prevents blown fuses which can lead to students receiving erroneous results. With the prompts from the myDAQ, students will be able to realize they are measuring a quantity wrong and will be able to correct it immediately without waiting for feedback in the form of a graded lab report.

2.) An understanding of, and an ability to apply, Thevenin and Norton's theorems.

Much like Kirchhoff's laws, Thevenin and Norton require validation from direct measurements.

3.) An ability to analyze 1st and 2nd order circuits

This includes understanding the behavior of circuits which contain resistors, capacitors, and inductors. Specifically, students should understand how current and voltage behave in such devices and the associated features such as the time constant.

4.) An understanding of sinusoidal steady state analysis.

The student will have unlimited time on their own to manipulate and explore sinusoidal wave forms. Students can even experiment with triangular and square wave forms. The flexibility of not having a time constraint on the lab will allow the student to test their own ideas without fear of running out of time to collect data with which to write their lab report.

As an important example one of the fundamental ideas a student exiting a basic circuits class should understand is that components in parallel have the same voltage and components in series have the same current. This is essential for measurements. A task students often fail to comprehend is that they must break the circuit and insert the meter in series to correctly measure current. Since measuring voltage in parallel is easier, students typically attempt to measure current in the same manner by simply setting the dial on the multimeter to measure amps. This usually results in a blown current fuse. Students often do not realize their mistake and will simply mark all currents as zero value. The myDAQ has a built in current limiter that will stop current so the device is not damaged. Students are given feedback by the device when they are using it incorrectly. When students use the device incorrectly they receive an error message. This notifies the students that something is amiss while also protecting the equipment from damage. Replacing blown fuses is time intensive. If a faulty meter is not identified, it becomes very frustrating for the student. The myDAQ can help prevent or limit such negative experiences. Additionally, the myDAQ provides a relatively safe environment for using AC sources. Its built in inhibition prevents equipment damage caused by minor missteps from inexperienced users.

The myDAQ will allow students to spend more time building first order circuits. They will have their own equipment and be able to experiment with how and where to measure a first order circuit. Being freed from the time and shared equipment constraint of the lab will allow the students to gain greater insight into the behavior of 1^{st} and 2^{nd} order circuit elements. For example, if a student wants to test a circuit design they have seen in their textbook they can do this with a myDAQ at home.

2 Discipline Based Education Research

2.1 What is Discipline Based Education Research

This dissertation broadly falls under the category of Discipline Based Educational Research (DBER), and the sub classification of Engineering Education Research (EER). This is an emerging area of international interest. The following information is intended to introduce the ideas of DBER and EER, to show how they fit into modern scholarly research in Engineering. According to Singer, Nielsen, & Schweingruber (2012) DBER is research that “investigates learning and teaching in a discipline from a perspective that reflects the disciplines priorities, worldview, knowledge, and practices”. They further specify that DBER is a “collection of related research fields”. It is also a very broad term collecting research across all STEM fields. Such research that focuses on the education as it relates to engineering disciplines is known as Engineering Education Research (EER). DBER work in some fields is well developed, as in physics. In others, it is just beginning to emerge. EER and DBER are also highly interdisciplinary in nature. The interdisciplinary nature of EER has led to its emergence as an area of international interest (Borrego and Bernhard 2011). The use of the terms DBER and EER are relatively new, first occurring in the literature during the early1990s.

Recent research which could be classified as DBER or EER in nature includes Rosenblatt’s (2012) work on student understanding and misconceptions in physics and materials science. Gordon Aubrecht (2013) has also recently published work relating to students conceptions of the structure of matter. Both of these studies focus on what beliefs students have about phenomena when they enter a class room and how to improve upon these conceptions through instruction. Within Wright State University several studies have been produced. Qian (2012) produced a thesis comparing inquiry based teaching methods in the US and China. In the College of Engineering and Computer Science there is an ongoing EER project which is focused on the improvement of engineering students' math abilities through instruction (Klingbeil et al. 2004, Klingbeil et al. 2005, Klingbeil et al. 2006, Klingbeil et al. 2007).

Though the above examples are quite recent, such research had a very long history. In 1893 the Society for the Promotion of Engineering Education was founded (Singer, Nielsen, & Schweingruber, 2012). This organization still exists today, though it is now known as the American Society of Engineering Education. There exists today organizations devoted to the development of rigorous standards for EER research (Streveler and Smith 2006). Several publications, such as *IEEE Transactions on Education* regularly publish scholarly EER research.

As technology advances, the principles of basic analog circuits are becoming more important to all of engineering. Students are entering our programs with many different backgrounds and learning styles, even when compared to just a few years ago. It is highly likely that any engineer graduating from a university today will need to understand the basic principles and practices covered in EE 2010L. It was expected that, students using the myDAQ would perform better at measuring current, voltage, and resistance in basic analog circuits containing resistors, capacitors, and inductors with both DC and AC sources. These students would also have a better understanding of the current and voltage relationship for resistors in series and resistors in parallel.

Simply knowing the basic tenets of educational theory would not be enough to carry out this dissertation. Duit et al. (2012) state that:

> "The interdisciplinary nature of science education is responsible for particular challenges for carrying out science education research and development. Not only sound competencies in science are necessary but also substantial competencies in various additional disciplines."

One of the major benefits of DBER and EER is that the research is conducted from the prospective of the discipline. A thorough grounding in engineering is required. A major part of improving education is showing students how it will connect to other parts of their studies. The design of the lab activities used is an important part of this dissertation. It is imperative to select and run lab activities that allow students to see how the lab activities relate to ideas and concepts beyond the course. Activities must be designed to educate Electrical, and Computer Engineering students for the ideas of high pass, low pass filters, etc. At the same time, the activities have to be meaningful to Mechanical Engineering students. It takes an engineering background to truly understand those connections. At the same time, educational theories on the foundations of learning are employed in the design to maximize student learning.

In particular, the theories of conceptual change were used when designing the lab activities. Conceptual change theory (Posner et al. 1982) posits that students enter a course with a certain set of beliefs and preconceptions about a topic. These concepts may be correct or completely incorrect. Students do not simply abandon their preconceptions but must rather gradually evolve their conceptual understanding based on experience.

DBER and EER are about pulling together the practices of educational theory and discipline specific theory to improve education. This dissertation incorporates the tenets of Electrical Engineering and Education to change the learning experience in EE 2010L Circuit Analysis Laboratory.

The National Research Council has published reports on the current progress of scholarly research in DBER. The National Research Council actively encourages more work in the field. DBER and EER have been mapped to ABET expected outcomes for engineering education (Singer, Nielsen, & Schweingruber 2012).

2.2 Engineering Education Research

In the 1990s, ABET introduced EC2000. EC2000 was a new set of curricular guidelines by which engineering programs would be accredited. The new guidelines were a shift in the review of engineering education programs towards an evaluation of programs based on student outcomes, quantifiable evaluations, and improvements of student performance (ABET 1995). This change occurred because it had become obvious that the previous curriculums and methods were not producing engineers capable of meeting the demands of the modern field (Lohmann and Froyd 2011). ABET (2011) specifically lists the following in regards to program assessment as part of its evaluation:

> "Assessment is one or more processes that identify, collect, and prepare data to evaluate the attainment of student outcomes and program educational objectives. Effective assessment uses relevant direct, indirect, quantitative, and qualitative measures as appropriate to the outcome or objective being measured. Appropriate sampling methods may be used as part of an assessment process."

These new methods of evaluation from ABET spurred development of Engineering Education Research (EER). New assessment instruments needed to be devised to evaluate attainment of outcomes and objectives. In general, EER does such assessment, and goes beyond this by incorporating theories of learning. It is about providing appropriate measures to evaluate the outcome under consideration. The purpose of this dissertation in particular is to produce quantitative measures to determine just how well students are learning to use the basic electrical engineering lab equipment and how to improve their understanding of the basic foundational concepts of relation for voltage and current for elements in series and parallel. Currently data is not collected from EE 2010L as part of the Electrical Engineering Department's ABET assessment efforts. It is important to collect data that can show if students are meeting the expected outcomes and objectives for the first course in analog circuits as part of their curriculum, be it for Electrical, Mechanical, or Computer Engineering students. Student preparedness is measured when they arrive in the follow up course, EE 3310. Scores on this pre-test as presented at a departmental meeting show a need for improvement.

In 2009, the American Society of Engineering Education (ASEE) with funding from the NSF produced a document, *Creating a Culture for Scholarly and Systematic Innovation in Engineering Education*, the purpose of which was to:

> "catalyze a conversation within the U.S. engineering community on creating and sustaining a vibrant engineering academic culture for scholarly and systematic educational innovation – just as we have for technological innovation – to ensure the U.S. has the right people with the right talent for a global society."

DBER is well established as scholarly work in other fields such as chemistry and physics, but has lagged in engineering. There is a noticeable lack of evidence-based educational research in Engineering (Graham 2012). We are now beginning to see growth in this area. EER has expanded with the introduction of new ABET criterion.

EER research uses previous work from education disciplines as the framework for engineering work. (Olds et. al. 2005) The foundational principles are applied to engineering research in the same manner the concepts from statistics, calculus, and linear algebra are applied to engineering research. They are a tool to further the study of engineering. As defined by ABET (2013) in Criterion 5b of the Criteria for Accrediting Engineering Programs 2014-2015 Engineering is about " devising a system, component, or process to meet desired needs." This is exactly what EER does. It develops the tools necessary to make an informed judgment about pedagogical method that can be disseminated nationally.

Even as an emerging field, EER has the hallmarks of a well defined and reputable field of inquiry. The American Society of Engineering Education (ASEE) is the largest professional organization devoted to issues related to EER. Even within IEEE, the leading professional organization for Electrical Engineering, there is an education society. There are several respected peer reviewed journals related solely to the topics of EER. Among these are *The Journal of Engineering Education*, *International Journal of Engineering Education*, *International Journal of Electrical Engineering Education*, and *IEEE Transactions on Education*.

Several institutions now have engineering education departments based within their college of engineering where the focus is on scholarly research in EER. Graduating students receive an Engineering Ph.D. In these departments, faculty hiring, promotion, and tenure are based upon scholarly work in engineering education. Purdue University was the first to establish an Engineering Education department in 2004 (Purdue University 2014). Other institutions with Ph.D. granting engineering education departments inside their respective engineering colleges include Virginia Polytechnic and State University (Virginia Tech), Arizona State University, and Clemson University. Graduates of these programs receive a Ph.D. in engineering. The faculty members of these departments are typically individuals holding a Ph.D. degree in a field of engineering. Most have listed research interests that are both technical and educational in nature. One notable researcher in DBER and EER is Dr. Eric Mazur from the Harvard College of Engineering and Applied Science. Dr. Mazur is nationally known for his work with nanoscale structures and his work with DBER. EER, like DBER, requires individuals to cross typical disciplinary borders. This is similar to technical based research which is not easily compartmentalized in the traditional scope of one discipline.

The impetus for the growth of EER comes from ABET's EC2000 guidlines. Prior to EC2000, much of the improvement in pedagogical methods had been based on intuitive ideas and trial and error methods of innovation (ASEE 2009). This new emphasis on empirical data to measure program effectiveness has led to new interest in empirical methods of educational innovation. As educational theory is not a typical part of engineering training, engineers will need to make contact and collaborate with others from other areas of the academy in order to produce reliable and valid measures (Borrego 2007, Cox 2009, McKenna, Yalvac, and Light 2009). Such collaboration is no different than a Mechanical Engineer consulting a Biologist when investigating flight dynamics of birds, or an Electrical Engineer consulting a Chemist when working on novel solid state devices.

In line with the mandates of EC2000 the Electrical Engineering Department at Wright State University routinely collects data on learning outcomes of courses. Based on this data, changes are made to courses. EE 2010L Circuit Analysis Lab, as an introductory course has never been studied in the same manner.

2.3 EER at Wright State

Wright State University already has an ongoing EER project on a much larger scale than the dissertation outlined herein. The EGR 101, now EGR 1010, course has been studied meticulously since its creation. The results have been published and presented widely (Klingbeil et. al. 2004, Klingbeil, et. al. 2005, Klingbeil, et. al, 2006, Klingbeil, et. al. 2007). EGR 101 has been a collaboration between most of the disciplines in the College of Engineering and Computer Science and the Math Department at Wright State. This shows that the groundwork for such collaboration has already been established successfully in the University.

Current models for graduate education mean most faculty members in engineering are not formally exposed to the ideas and theories of teaching and learning. They can be referred to as "gifted amateurs" (Kuh 2008). As Ambrose and Norman (2006) note, the science and understanding of the level of complexity of the learning process has grown significantly in the past 20 years. It is now widely accepted that the process is interrelated to many factors. However, the ideas of teaching and learning theories have not been adequately distributed or introduced to the entire faculty. ASEE (2009) says that a supportive environment and broad collaboration are the most important factors in order to establish successful and lasting EER on campus. Faculty members must be willing to move beyond the traditional scope of their discipline and cross over into other areas to improve teaching. Given the extensive work in EGR 101, a supportive environment is well established. This dissertation builds collaboration across universities and departments.

Many of the premier engineering colleges in the U.S. have active EER taking place on their campus. Whether this be in the form of a separate school, department, or faculty research area.   Several leading universities are beginning the process of flipping their beginning circuits courses to improve student outcomes. Texas A&M has experimented with at home labs to improve student success early in students academic careers and, in a collaborative project, Kansas State University and East Carolina University have both moved to an inverted lab structure (Yao et. al. 2010 and Sharad and Robbins 2010). This dissertation, and the use of the myDAQs, is an attempt to expand upon the educational research already occurring within the College of Engineering and Computer Science.

3 Experimental Design

3.1 Research Goal

As noted previously, the percentage of students receiving grades of F, X, or W has been in higher in EE 2010L than in the previous incarnation of the course in EE 302 which was run on the quarter system. A new instructional method was developed in an attempt to improve student performance. This dissertation evolved as way to measure the effectiveness of the new instructional method.

An investigation was conducted to compare the effectiveness of the new instructional method with the traditional lab instructional method. An established evaluation, the ECCE (Thornton & Sokoloff) was used as a pre-test and post-test. Two instruments, a midterm lab practicum and a final lab practicum were developed to measure student lab skills. These instruments were used to obtain measures for comparisons between the two instructional methods. For the majority of the term the two groups completed the same weekly lab activities.

3.2 Methodology

Two groups were established. The first group was a control group, which performed lab activities in a traditional bench lab setting. These students used standard lab equipment and took measurements during lab time. The second group was a treatment group. This group used an inverted lab structure to perform the weekly lab activities.

A quasi experimental design was used to allocate students between the two groups. Given the complexities of student scheduling it is impossible to randomly assign students to lab sections. There are other courses students must take, work schedules, family commitments, and other outside activities.   Quasi experimental means that things have been randomized as much as possible. In order to maximize the randomness of student enrollment, twin lab times were used.   There were eight sections of lab offered during the semester. The sections were paired, one odd numbered control group (bench lab) with one even numbered treatment group (myDAQ lab). The sections met at the same time but in different rooms. In the online registration systems students were not able to see which labs are myDAQ sections and which are bench labs. The twin times are used to get as random an enrollment as possible. This minimizes the impact of student major on enrollment in other required courses on student section selection. If, for example, Mechanical Engineering students are only able to register for lab on Tuesday at 12:30, there is both a myDAQ and a bench lab section at that time, so randomness of enrollment is maximized. This was to help prevent from having skewed demographics between the bench labs and myDAQ labs.

Students completed the lab midterm and lab final practica on equipment they did not use to collect their weekly data.   The use of equipment students did not use on a weekly basis was intended to show their mastery of the concepts and in the ability to apply it in a new setting.

In running both control and treatment groups in the same semester allows for direct comparison. Such direct comparisons will yield usable results. Students' experience same lecture conditions, are at the same point in their academic program, and are only differentiated by the method of instruction.

3.3 Data Collections

Several assumptions were made when collecting the data. The first assumption was that the student demographics between the bench labs and myDAQ labs would be similar. That is to say it was expected both groups would have similar distribution of student majors and of student GPAs. If the two groups have equal demographics the direct comparisons can be made between the outcome in the bench labs and those in the myDAQ labs. Based on the manner in which registration was conducted and the enrollment numbers in the section this was assumed to be true. As will eb shown later this assumption was indeed true.

Another assumption which was made relates to the lab practica. Students were given the practica on different days. It was assumed that the day the student took the lab practica did not impact their score. As the practice contained material which students could not "cram" for, but instead needed a thorough understanding of in order to perform well. The practica were taken on equipment which the students did not use regularly. They were not allowed access to the practica equipment to study prior to the midterm or final.   A similar assumption was made in regards to the administration of the pre-test and post-test. Students were not given feedback on their result of the pre-test. They were given full marks for completing the exercise. Students were not told the name of the exam so they could not search for the correct results. Given the comprehensive nature of the ECCE exam it was assumed the day on which the student took the exam did not have an impact.

3.3.1 Data Collected

Some data was collected on a weekly basis. Students in the myDAQ lab section completed a weekly survey (that can be found in Appendix E) providing information on whom they collaborated with and how much time they spent on the labs. Students in the bench labs completed a time log each week in the lab section to determine how long they spent on the activity.

During Week 6 a lab practicum midterm exam was given and during Week 12 a lab practicum final was given. In Spring 2014, all students performed the midterm and final on lab equipment which was foreign to them. Both the lab practicum midterm and lab practicum final can be found in the appendices C and D. The equipment used by all students during Spring Semester of 2014 to complete their lab practicum midterm and lab practicum final were as follows:

- Vellman DVM850BL Digital Mulitmeter
- Agilent E3630A Triple Output DC Power Supply
- Agilent 546224A Oscilloscope
- Agilent 33220A 20MHz Arbitrary Waveform Generator

By using equipment they were unfamiliar with, it was easy to see if the students could take the skills they learned and transfer them to other areas. Bao et al. (2009) state that to "[t]he STEM education community considers that transferable general abilities are at least as important for students to learn as is the STEM content knowledge." Results will show not just can the students use their equipment but do they know the skills well enough to apply them elsewhere. As some of the myDAQ tools are virtual in nature, it will show their ability to use traditional bench equipment. The midterm, included as appendix C, consists of measuring the resistance of three resistors, placing them in series, and then connecting to a power supply. The students were then tasked with measuring the voltage drop across and current through each resistor. Then the three resistors were placed in parallel and again voltage drop and current in each was measured. The final consisted of measuring voltage drops and current in a simple combination circuit, some resistors in series and some in parallel, and measuring for the time constant in an RC circuit connected to an AC source. The final is also included as appendix D. Students signed up to take the midterm and final outside of regularly scheduled class time. This meant that students from both bench labs and myDAQ labs were taking the exams at the same time, in the same room, mostly with an instructor they were unfamiliar with. This was primarily done due to limitations on the amount of available equipment. This also had the added benefit of minimizing the affect the instructor had upon the scores for the midterm and final exams.

In Spring, students also took the Electric Circuits Concept Evaluation (ECCE) as a pre-test at the beginning of the term and as a post-test at the conclusion of the term (Thornton, R., & Sokoloff, D.). This test was originally developed and validated and has since undergone several revisions. Several studies have shown the ECCE to be a reliable and valid metric (Pendergrass et. al. 2001, Efthimui et. al. 2011). The ECCE includes 41 multiple choice questions and 4 short answer questions. It has been used in several other studies as an acceptable measure of student understanding of fundamental circuit theory concepts (Pendergrass et. al., 2001). The use of the pre- and post-test served two purposes. First, ECCE established a baseline of student knowledge. It also established what concepts the students knew well and what misconceptions they had at the beginning of the course. It is important to establish such misconceptions (Duit, Treagust, & Widodo, 2008). Secondly, it served to notify the student of the rigor of the course and prepare them for the type of material they will encounter (Smaill et. al 2012). A comparison of pre-test and post-test scores allowed for analysis of how well misconceptions had been corrected. As the pre-test was taken in the first week of classes it is assumed that there will be no significant difference in scores between students taking it in the beginning of the week (Tuesday is the first lab day of the week) and those taking it at the end of the week (Thursday is the last lab day of the week). Similarly, the post-test was administered to everyone during the final week of regular classes before finals. Again it will be assumed there will be no statistical significance difference between which days the test is taken. The test measures concepts taught over an entire 15 week term and not material which can be quickly covered in a matter of days. For this reason, the day on which the pre-test and post-test were taken will be considered insignificant. The test items all aligned with material which was to be covered by the courses. Given the alignment between test questions and course learning outcomes the students' total score was used.

It was expected that students using the myDAQ would spend more time on the activities. There are a few reasons it is expected students will spend more time. It is theorized that students will spend more time "tinkering" and playing with circuits.

Answering their own questions of "what happens if I do this?". Secondly, there is failure. If a student does not have a TA to turn to for immediate correction they are more likely to try small changes to attempt to "fix" their own circuit. The more time spent on the activity will translate into better proficiency with the equipment and a better understanding of the material rather than giving up and waiting for the TA to come solve the problem. Further, it is expected that students who used the myDAQ will have higher scores on the midterm lab practical, final lab practical, and the post-test. It is also expected that students who used the myDAQ post bigger gains from the pre-test to the post-test.

3.4 Weekly Lab Meetings

Weekly assessments of students' work were done through the written lab reports students submitted. Each week, students in the myDAQ sections, were expected to individually carry out their experiment, obtain data, and write a lab report summarizing the results. During the course meeting time, students were selected at random to demonstrate how they performed a part of the experiment. These unannounced presentations served as an incentive for students to stay motivated and current with their experiments. Students in the myDAQ sections completed weekly surveys asking how long they spent collecting data, if they sought assistance from anyone, and who did they get assistance from. Students in the bench lab sections signed an attendance sheet each week and listed what time they left the lab. From this list the amount of time the student spent collecting data could be determined. This allowed for determination of how long each group spent on the lab activities.

To augment the student learning experience, there was open lab time throughout the week. The open lab time was for students to come and ask specific questions about the experiment for that week. The open lab time was staffed with graduate teaching assistants and undergraduate students who have previously completed the course using the myDAQ. Graduate teaching assistants used in the course were given myDAQs during the fall term so they would have ample time to become familiar with them. The teaching assistants were instructed to perform all the labs in advance of Spring Semester. Weekly instructional meetings were held with the teaching assistants to address questions about the coming week's lab activity. Further, unannounced observations of the teaching assistant in their lab sections and open lab times were carried out. If, after the lab section concluded, there were any areas of concern, the teaching assistant was given a verbal quiz and asked to demonstrate task and ideas. These demonstrations were used as confirmation of the students' completion of the lab activity. They served as a basic check to ensure students were collecting their own data.

The two lab sections were conducted differently. Time spent in each lab was different and the allocation of time was divided differently. Shown below is how the tasks for each weekly lab activity were accomplished in the two groups:

	Control	Treatment
In Class	Lecture by TA Collection of Data Copy of Data given to TA	Lecture by TA Demonstration of Lab Skills
Outside Class	Lab report Written Individually	Collection of Data Individually Lab report Written Individually

Table 3.4.1 Division of Activities in Weekly Lab Meetings

3.5 The myDAQ

Data Acquisition devices (DAQs) are common in many research labs. The myDAQ is a student version produced by National Instruments. The myDAQ has two analog inputs, two analog outputs, seven digital input/outputs, three power supplies, audio input/output jacks, and banana plug jacks for a digital multimeter (National Instruments Corporation, 2011). Students were provided with a breadboard that plugs into the myDAQ. Figure 1 below shows the myDAQ and breadboard issued to students in the myDAQ sections of EE 2010L Circuit Analysis Lab.

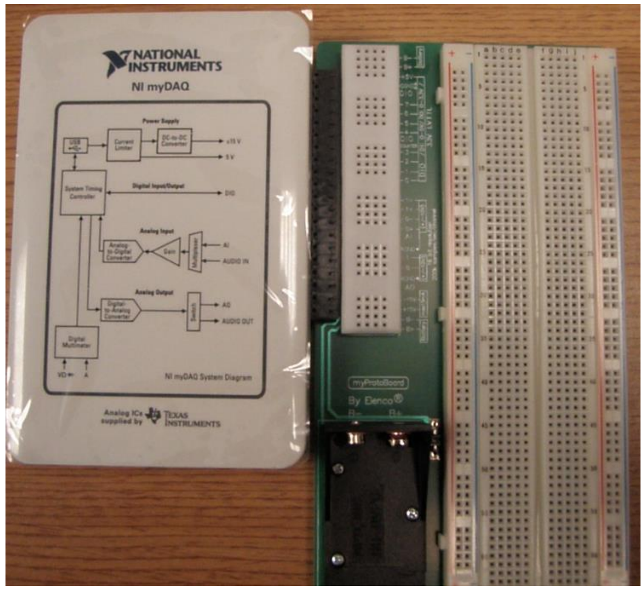


Figure 3.5.1 myDAQ with breadboard

The myDAQ comes with software for a digital multimeter, power supply, etc. Figure 3.5.2 below shows the DC power supply and measurement of the voltage drop across the resistor with a myDAQ. Figure 3.5.3 shows the frequency generator and oscilloscope that the students use with the myDAQ.

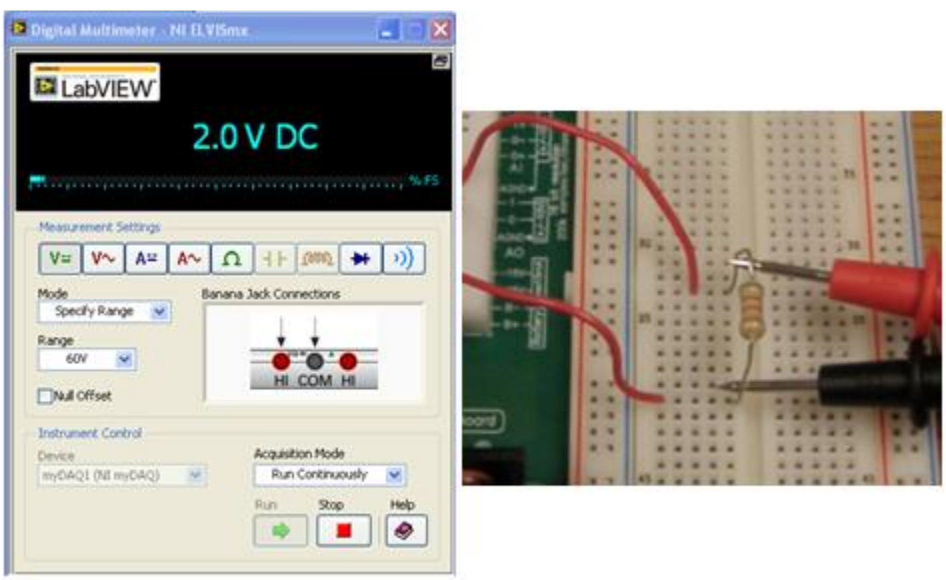


Figure 3.5.2 myDAQ DMM display of physical measurement

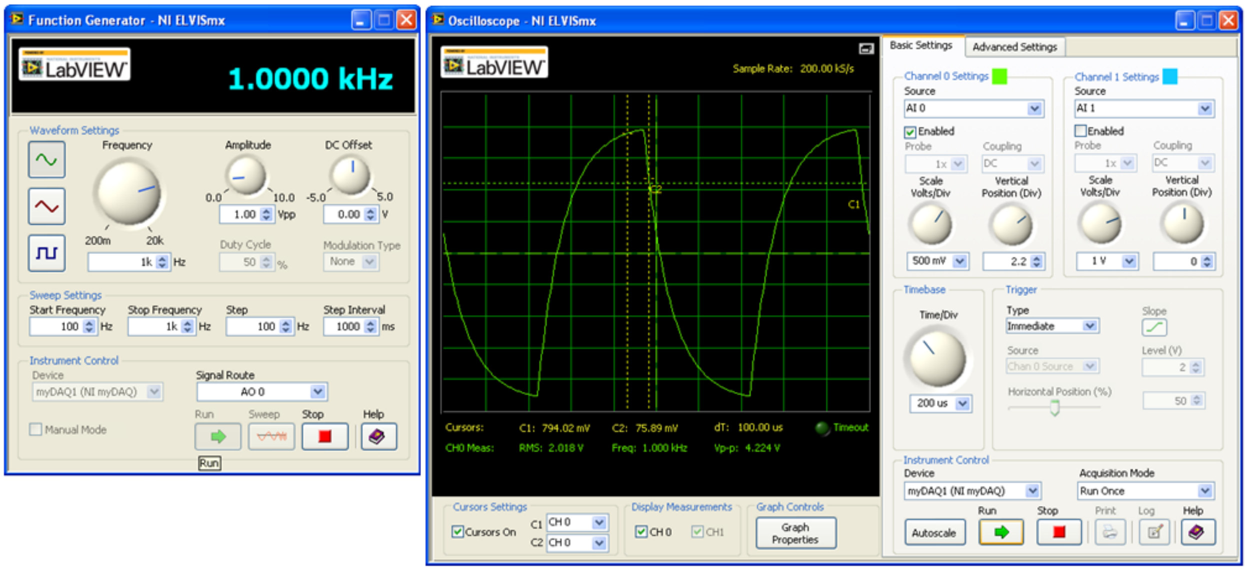


Figure 3.5.3 myDAQ Frequency Generator and Oscilloscope display

Students physically build resistor, capacitor, and inductor networks on the breadboard the same way they would on a traditional lab bench. The only difference is that instead of connecting to a traditional power supply and multimeter the myDAQ allows the students' computer to serve both of those purposes. This makes the lab portable. Students can take it anywhere, allowing students to extend the exploration and inquiry with the lab equipment. It also frees the students from time constraints imposed by a bench lab.

One challenge that occurs in the bench lab is students will try to measure current in parallel with the resistor. This results in a blown fuse in the multimeter. Often students do not realize this and continue to record inaccurate measurements due to the blown fuse. The myDAQ is more robust and this problem does not occur with the size of the power supplies used in EE 2010L. If there is a problem with the equipment, the software displays a clear text error message.

The myDAQ can also be used for AC circuits. Several labs investigated phenomena related to AC circuits. It has a frequency generator and oscilloscope. Students performed the same labs and received the same experience on the myDAQ they would perform on the bench equipment but in an open ended environment. The open-ended environment allows for more time and student exploration. Such exploration can lead to new connections between the concepts.

Students were issued a Department-owned myDAQ for use throughout the semester. Students were responsible for the care and handling of the myDAQ and were expected to return it at the end of the term. The cost is also an added benefit. The myDAQ and breadboard provided to the student cost approximately $250, $200 for the myDAQ and $50 for the breadboard. A standard bench lab set up including all components used throughout the semester can cost nearly $10,000. For the cost of outfitting a basic circuit analysis laboratory with ten stations with brand new equipment, 400 students can be provided with a myDAQ and breadboard. If the myDAQ is adopted across multiple courses, students can be responsible for purchasing their own so they may use it across courses.

3.6 Development of Weekly Lab Activities

Both groups performed the same weekly lab activities. These lab activities were designed so that both groups were using the same components and circuits. All weekly lab activities were specifically designed for this dissertation. Various sets of lab activities had previously been created for the course when it was EE 302. Through the years several iterations of the activities had been written. When the course changed to EE 2010L with the semester conversion the labs were amended again. As a result, there existed a series of lab activities that had been through several editions, but were deemed to be inappropriate for the course in its current form. As noted previously, prior to the semester conversion, the course had a prerequisite physics course which introduced the basic ideas of circuit theory. As part of the lab experience for this physics course students had exposure to the basic lab tools. After the semester conversion, this prerequisite was dropped. This meant some students were coming to EE 2010L without any prior exposure to the basic lab tools. The existing lab activities relied on the assumption students had this prior exposure.

Additionally the many edits and revisions had produced lab activities which did not fit well together. Students often felt the labs had little relation to the accompanying lecture course EE 2010. This was true as the sequence and pacing of lab activities did not match those of the accompanying lecture. These lab activities were compiled and formatted most recently at the conclusion of Fall Semester 2012 (Hance, 2012). These were used as the starting point for lab activities that could be used with the both a traditional lab and an inverted lab.

The first step involved ordering the lab activities so that they followed the introduction of material in the accompanying lecture courses. The lab activities were sequenced as follows:

Week	Activity Topic
1	Pre-Test
2	Basic Lab Tools and Techniques
3	Constructing a Real Circuit Using IC Chip and LED
4	Resistive Circuits in Series and Parallel
5	Combination Resistive Circuits
6	Resistive Voltage and Current Divider Circuits
7	Lab Practicum Midterm
8	No Class Spring Break
9	Node Voltage and Mesh Current Techniques
10	Thevènin & Norton Equivalents
11	AC Lab Tools and Techniques
12	RC Circuits
13	RL and RLC Circuits
14	Lab Practicum Final
15	Post-Test

Table 3.6.1 Schedule of Weekly Lab Activities

This resulted in the removal of some labs and the creations of new lab activities related to AC signals. The remaining labs were all rewritten to make their level of academic rigor follow that of the level to which the material was now taught and introduced. The sequence for activities was designed to align with the sequence and timing when students are introduced to the concepts in the accompanying lecture course. Lab activities were also written to challenge common misconceptions. One of the most accepted theories on learning (Posner et al. 1982) posits that students do not simply acquire and use new knowledge as it is presented to them. Rather there prior conceptions about phenomena must be changed.

Student conceptions do not easily or readily change (Rosenblatt 2012, Duit, Treagust, & Widodo, 2008). Students must assimilate new evidence into their pre-existing conceptions. If the evidence is opposed to prior conceptions a change can be produced (Treagust & Duit, 2008). As more and more new evidence is assimilated the students' conceptions will gradually change. An example of this can be seen in Lab activity 2 (appendices H and I). In this lab activity students use a DC power source, and LED, some resistors, a capacitor, and a 555 IC timer chip. When students connect the circuit correctly the LED blinks. As they try to measure voltage across the resistors they see that it varies. A common misconception is that when a circuit has a DC source everything is constant. This activity presents student with evidence in direct conflict with the notion that things are constant in DC circuits. Students must accommodate this new occurrence of varying signal in a DC circuit with their previous constructs.

Another factor in the rewriting of the lab activities was that they would be used on two different sets of equipment. Students in the control group used the following equipment:

- Tenma 72-1020 Digital Multimeter
- Agilent E36314 Triple Output DC Power Supply
- HP 54600B Oscilloscope
- HP 33120A 15MHz Arbitrary Waveform Generator

Students in the treatment group used the National Instrument myDAQ and the accompanying ELVISmx software to collect data.

The two sets of equipment had different settings and tolerances which result in different functionality. One of the primary differences was with current output. The myDAQ has a current limiter that will only produce 2.3 mA of current. Regardless of the output current setting, the myDAQ will not produce more than 2.3 mA. The Agilent E36314 Triple Output Power Supply used in the bench labs is rated at 0 to 5 A or 0 to 1 A; depending upon the output used. This meant all circuits needed to be analyzed to ensure that no current of more than 2.3 mA was needed in any of the branches. If, for example, a myDAQ is set for 10 V and a 100 Ω is connected in parallel with it, the voltage will adjust down so that only 2.3 mA of current is produced. The display for the variable power supply will still say 10 V. This can lead to a great deal of confusion among students. Similarly, if more than 5 mA of current is produced in the bench lab, the fuse on the multimeter will blow. Other issues were also accounted for in the design of the weekly lab activities. The Agilent power supply can produce 10 mA, but the Tenema multimeter only has a fuse that can handle 5 mA of current. The Tenema multimeter will not read error when the fuse blows, but will only display values of 0.000. Students often interpret this to mean the value they are measuring is 0.000, not that there is an error.

There was also another difference between the myDAQ and the Agilent power supply which proved a design challenge. The Agilent has three variable outputs. The outputs have limits of 6 V, 25 V, and -25 V. The myDAQ has only one variable power output, -10 V to 10 V. It also has a 15 V output and -15 V output that are not variable. This meant that if a circuit needed two power supplies only one could be variable and the other had to be either -15 V or 15 V.

Challenges also arose with other equipment. The HP 54600B oscilloscope used in the bench lab had a continuous run display. While the oscilloscope for the myDAQ had a single pass option. AC circuits had to be designed for continuous run at the lower resolution of the HP oscilloscope. Another challenge with the equipment was the HP arbitrary waveform generator used in the bench lab has an AC power supply. The expected operation of it included a 50 Ω resistor being connected in parallel across the supply to create a Norton equivalent. All these factors had to be considered in the design of the weekly lab activities so that students had the same experience regardless of if they were in a control or treatment lab section.

Two sets of lab activities were produced, one for control group and one for treatment group. The lab activities can be found as appendices F through W. The only difference between the two sets was the instructions for how to use the equipment.

3.7 Weekly Lab Operations and Teaching Assistants

As previously mentioned, the lab activities required students to obtain the same set of measurements for the same circuits. Given that there were two different sets of equipment, each group, Control and Treatment, had slightly different directions specific to their equipment. The bench and myDAQ labs also functioned differently from week to week. One critical factor for the lab operations was the Teaching Assistants (TAs).

The TAs were the ones who fostered the lab environment. There were five TAs involved in the labs. In order to preserve their anonymity they are referred to using phonetic alphabet, Alpha, Bravo, Delta, Echo, and Foxtrot. Alpha and Bravo taught both bench and myDAQ sections. Alpha taught two myDAQ sections and one bench section. Bravo taught one myDAQ and one bench section. Delta and Echo taught one bench section each. Foxtrot taught one myDAQ section. In Appendix A the TA is one of the identified data points for each student. In the data analysis the TA was identified as an independent variable which could impact the learning outcomes.

During the collection of data the TAs were assumed to be equal and no special weight was given to work and grading of any one TAs. That is to say no score adjustments were made based on which TA was assigned to a lab section. Each week a weekly lab meeting was held for all TAs. Each week they received prepared set of notes for the following week's lab activity. The notes were different for those teaching bench and those teaching myDAQ sections. Alpha and Bravo received notes for both bench and myDAQ. The author of this dissertation, who was also the course instructor, was also involved in these weekly meetings and provided feedback and expectations to the TAs for how to conduct the lab the following week. Additionally, discussions provided feedback from instructor's observations of the previous week. All teachings assistants were aware that they were partaking in collection of data for this dissertation.

When the TAs conducted the labs, they conducted them differently depending upon if they were a bench or a myDAQ lab. The bench lab began with a 10-15 minute introductory lecture by the TA. This lecture was from the notes provided in the weekly meetings with the instructor. In this lecture the TA demonstrated how to use the equipment for the week and clarified any potential pitfalls students may encounter. At the conclusion of the lecture the students commenced the collection of data in groups of two. During this time, the TA migrated throughout the room answering student questions and fixing equipment which malfunctioned. As students completed their collection of data they submitted a copy of their results to their TA. Data was collected on carbonless paper with student responsible for the format and layout of the data. Then students signed out indicating which time they left the lab. The TA remained in the lab till all students finished collecting data.

The myDAQ were conducted differently. They also began with a 10 to 15 minute introductory lecture by the TA. In this lecture the TA presented a pre-built example of the circuit under consideration for the week's activity and clarified any potential pitfalls students may encounter. This lecture was from the notes in the weekly meeting with the instructor, these notes were very similar to the bench lab notes, only differing due to equipment differences. After the lecture, the TA would randomly call upon students to ask demonstrate lab skills form the previous week's lab activity in front of the class. The students went to a computer with an attached myDAQ connected to a projector so all the students could see what was occurring. Once all the previous week's lab skills had been demonstrated the entire class was dismissed. The students then collected the lab data independently outside of class time. Each student had their own myDAQ and were able to collect it individually. The TAs for the myDAQ sections were also required to hold open lab times in the teaching lab throughout the week. Each myDAQ TA was responsible for one hour of open lab time per week. During these open lab times, the students in the myDAQ section could come for help if they were stuck on a particular part of the lab activity. In a typical week 2 to 3 students would show up for each open lab time. Table 3.7.1 below shows how time was spent in the two lab types.

	Time spent in lab on activity	
Activity	Bench	myDAQ
Intro lecture	10-15 min	10-15 min
Collection of Data	up to 135 min	0 min
Demonstration of Skills	0 min	10-20 min

Table 3.7.1 Time Spent on Various Activities in Lab

In table 3.7.1, it can be seen, that the time was allocated differently in the bench and myDAQ labs. The myDAQ labs were only meeting for approximately 35 minutes. The bench labs were often running for 100 minutes or more.

Given the differing lengths of time spent in the lab, the interaction with the TA was different in the two sections. In the bench labs, students were able to ask questions and interact with the TA as the collected data. In the myDAQ labs, the interaction was different. The student had to seek out the TA to ask questions, during the TAs designated open lab times.

Additionally, the TAs were important in the design and implementation of the lab practica. Students signed up for time slots for the midterm (available in Appendix C) and final (available in appendix D) lab practica that were outside of normal class meeting times. Slots were open to any student. During each time slot a TA administered the lab practicum. The result of allowing students to select their own time slot was that myDAQ and bench students were taking them in the same room at the same time. Students may or may not have been taking it with their regular TA. Students did not necessarily know the TA in the room and the TA may not have known the student. This meant the TA did not know if the student regularly used bench equipment or a myDAQ to perform weekly lab activities. TAs graded the papers for students who took the practicum during their time slot then returned to the student's regular TA so the grade could be entered in the grade book. This was done to reduce the effects of TA grading styles on the outcome.

A grading rubric was provided to the TAs for the lab practicum midterm and lab practicum final. The rubric was very specific. It listed a very narrow range of experimentally measured values which were acceptable. Each possible answer was assigned a point value, answers were marked as either correct for full points or incorrect for zero points. Such a rubric was used to reduce variation in the grading between TAs.

4. Time on Weekly Lab Activities

4.1 Weekly Lab Meetings

Students in the control group and students in the myDAQ group were expected to spend differing amounts of time in the lab, for the weekly lab activities. Students in the control group began lab each week with a short 10 to 15 minute lecture about the lab activity. Then the students worked in pairs to collect the data. Once students had collected the data for the week they turned in a copy of their data to the TA and signed out of the lab.

Students in the treatment group also received a 10 to 15 minute lecture on the week's lab activity. Then students were selected at random to demonstrate techniques from the previous week's lab activity. Once the demonstrations were over the entire class was dismissed. Each of these students was to collect data on their own each week outside of class time. Students were only present in the lab for approximately 20 minutes each week. Students could supplement this time by attending open lab times throughout the week if they so choose.

4.2 Measurement of Time on Weekly Lab Activities

Students in EE 2010L Circuit Analysis Lab have a wide variety of prior exposure to basic analog circuits. This presents a challenge for how to create lab activities that are of an appropriate length. There needs to be a balance between labs being too long for students with no prior exposure and too short for students who have had a great deal of prior exposure. Given this, it was felt that monitoring time students spent collecting lab data was important. For students in the bench lab this time was measured each week with a signature page. As students would leave the lab for the week they were required to sign out and list the time that they left the lab. Students in the myDAQ sections completed a weekly survey asking them to how much time they had spent in the collection of their data.

Students did not collect data during lab time in the myDAQ sections. Lab time was spent with the course teaching assistants showing a demo circuit and covering common errors on the lab activity. Students were asked to perform the lab activity on their own during the week. Then some students were selected at random to show how they set up their circuit for the previous week's lab activity and demonstrate how they used it to collect data.

A long term goal of instruction in EE 2010L is to move toward opened ended problem based labs. Such labs would require students to obtain much of their data outside formal class time. For this reason, attempts were made in this study to remove the pressure of time constraints from the lab. It was expected that removing the time constraint would allow students to be more detailed and cautious in their work. Further, it was hoped that outside of class, students would feel empowered to conduct their own trials and experiments with the materials. If the students could take the equipment home, they have unlimited time to experiment. They might also try things they would be afraid would "get them in trouble" if they attempted them in the formal lab setting. Due to the above stated reasons it was decided to have the treatment group collect their data outside of class.

Students in the bench lab section were given the same type of introductory lecture from the teaching assistant as the treatment group received. However, the control group then collected the data in pairs during the lab time. Before leaving the lab students were required to submit a copy of their data to the teaching assistant for verification. Bench lab section times include the time spent by the teaching assistant explaining the lab. This time is not accounted for in the times reported by students using the myDAQ. This time is minimal and likely has a very low impact on the overall time. Students using the myDAQ self reported time and these times may be slightly inflated or deflated. For example, a student may have only spent 55 minutes but rounded it in their head to report it as an hour spent collecting lab data. Some students may not have not known an exact time and simply “guesstimated”.

Bench Sections Time on Weekly Lab Activities in Minutes										
	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5	Lab 6	Lab 7	Lab 8	Lab 9	Lab 10
Mean	47	67	52	56	42	70	56	33	45	49
Median	45	66	50	49	45	60	51	30	45	45
StDev	8	18	13	22	12	30	23	14	12	21
High	70	105	70	105	70	116	108	65	65	95
Low	30	37	30	30	19	30	27	5	25	24
Count	44	34	23	44	54	54	48	59	61	47
Std Error	1.2	3.1	2.7	3.3	1.7	4.0	3.4	1.8	1.5	3.0
MyDAQ sections Time on Weekly Lab Activities in Minutes										
	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5	Lab 6	Lab 7	Lab 8	Lab 9	Lab 10
Mean	57	83	72	79	78	93	90	65	76	72
Median	60	90	60	60	60	60	60	60	60	60
StDev	37	39	37	43	57	58	66	46	44	28
High	240	210	210	240	300	300	360	300	240	150
Low	30	30	30	30	20	30	30	15	20	15
Count	30	46	45	46	55	54	56	52	54	52
Std Error	6.8	5.8	5.5	6.4	7.7	7.9	8.8	6.4	6.0	3.9

Table 4.2.1 Aggregate Time on Weekly Lab Activities Data

Shown above in Table 4.2.1 is a summary table of the time on task for the weekly lab activities. The table list the average time spent, the median time spent, the standard deviation of time spent, the maximum time, the minimum time, the count of students reporting a time that week, and the standard error. The maximum time is the largest reported time spent on the lab activity and the minimum time is lowest reported time spent on the lab activity.

4.3 Time on Weekly Lab Activities

There are several things to be noted about the data shown in Table 4.2.1. The standard deviation is higher among the myDAQ section than among the bench lab sections. The time for the myDAQ section is self reported and students were more likely to round numbers. The bench labs had a standard uniform sign out and were more cognizant of the time they had actually spent on the task, giving a known start time for the lab section. The count varies from week to week and shows the number of students reporting a time. The count variation is expected. Each week some students may miss a class for various reasons such as illness, pressing family concerns, or university sponsored activities. There were also several days where the University closed due to winter weather. In this case, students in the bench lab made up two labs the next week. Time for bench lab sections doing two labs was excluded from the summary table. This was excluded as students performing two lab activities may hurry through them in a quicker manner than they would if they were only doing one lab activity for the week.

Overall, the data is useful for drawing some inferences about student time on task and making comparisons between the traditional lab and the new pedagogical method of lab.

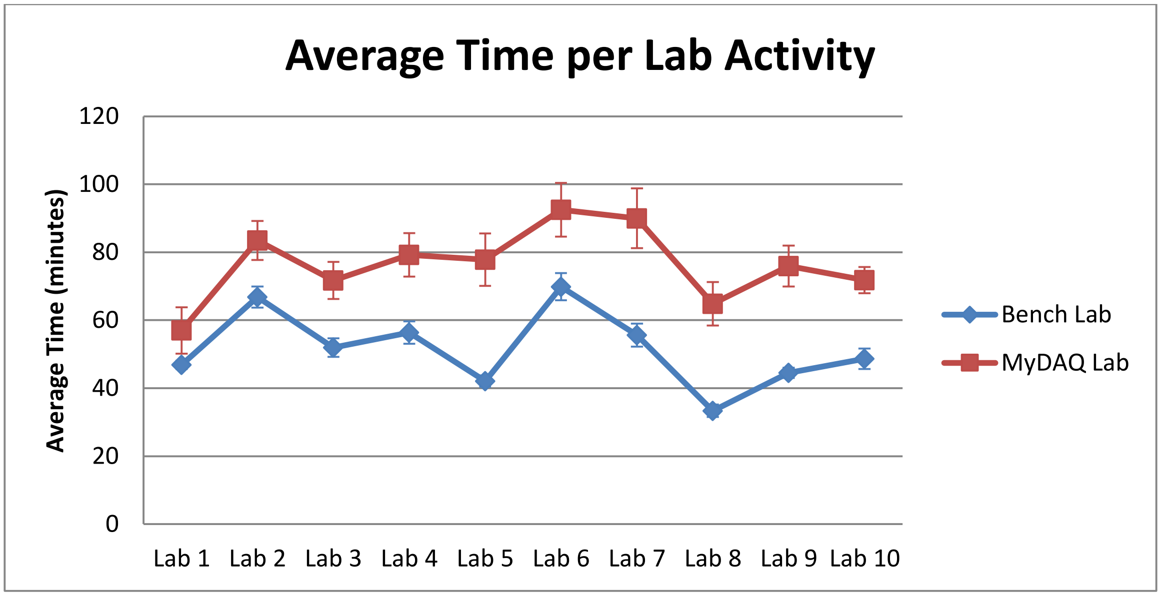


Figure 4.3.1 Average Time per Lab Activity

Above is Figure 4.3.1 showing the average time spent on lab activities for both the bench lab sections and the myDAQ lab sections. The error bars on each data point represent the standard error for that lab activity. Each and every week the average time of students in the myDAQ section was greater than the average time in the bench lab sections. Typically there is a 15 to 20 minute difference.

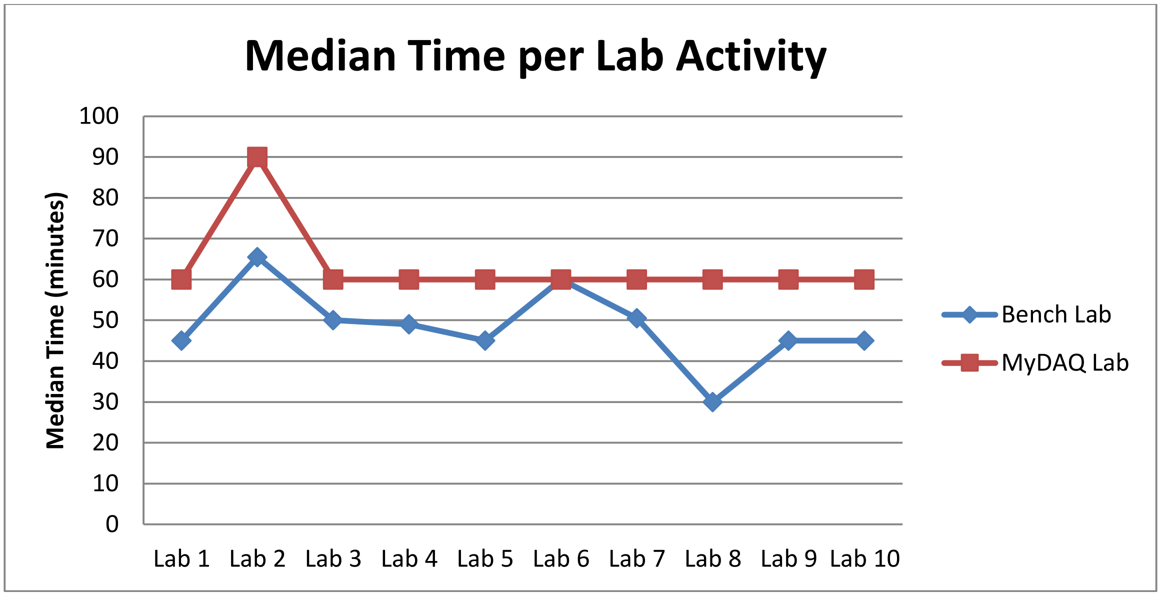


Figure 4.3.2 Median Time per Lab Activity

In Figure 4.3.2 we see that when considering the median time spent on the lab the students in the myDAQ sections reported spending more time on the lab activities than students in the bench lab. Lab Activity 6 produced the same median lab time for both groups of students. In the myDAQ sections, the median time was 60 minutes for all but one lab activity. There was much more variation in the bench lab sections. Lab Activity 1 and Lab Activity 8 are introductory labs and the low bench times are expected. The full lab activities are available as appendices F through W. Lab Activity 1 is an introductory lab and uses very basic functions of DC power supply and digital multimeter. Lab Activity 8 is an introduction to the tools used for AC circuits and is an introduction to the frequency generator and oscilloscope.

The question should arise of why not simply make the lab activities longer. The data above represents the mean and median time in the lab. As mentioned previously, students enter EE 2010L from a wide variety of backgrounds. Some have extensive experience with basic analog circuits and some have zero experience. This leads to a wide variation between the amount of time students spend collecting lab data each week.

Perspective may be gained by comparing the times of everyone in the control group to those spending the longest time collecting data and to those spending the least amount of time collecting data. The times for all students in all sections were combined and ranked from longest to shortest duration. The top quartile and bottom quartile of times were investigated. Shown below in Table 4.3.1 is the top and bottom quartile of times students spent in the bench labs each week.

	Bench Sections Highest 25% Time on Weekly Lab Activities in Minutes									
	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5	Lab 6	Lab 7	Lab 8	Lab 9	Lab 10
Average	57	89	67	86	58	109	89	52	59	78
Median	59	85	67	80	58	109	85	48	60	75
StDev	8	11	2	13	6	5	13	9	2	14
Count	11	9	6	11	14	14	12	15	15	12
Std Error	2.3	3.6	1.0	3.8	1.6	1.2	3.8	2.2	0.6	4.2
	Bench Sections Lowest 25% Time on Weekly Lab Activities in Minutes									
	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5	Lab 6	Lab 7	Lab 8	Lab 9	Lab 10
Average	39	46	35	32	27	37	29	16	29	28
Median	38	51	35	30	30	40	30	18	30	30
StDev	5	7	3	4	5	7	1	6	2	3
Count	11	9	6	11	14	14	12	15	15	12
Std Error	1.6	2.2	1.2	1.1	1.2	1.8	0.4	1.6	0.5	0.8

Table 4.3.1 Bench Sections Top and Bottom Quartile of Time on Weekly Lab Activities in Minutes

The table shows a pretty significant difference between these groups. In cases where 25% of the total was not a whole number, the number was rounded up to the next whole number to obtain the values shown in Table 4.3.1 above.

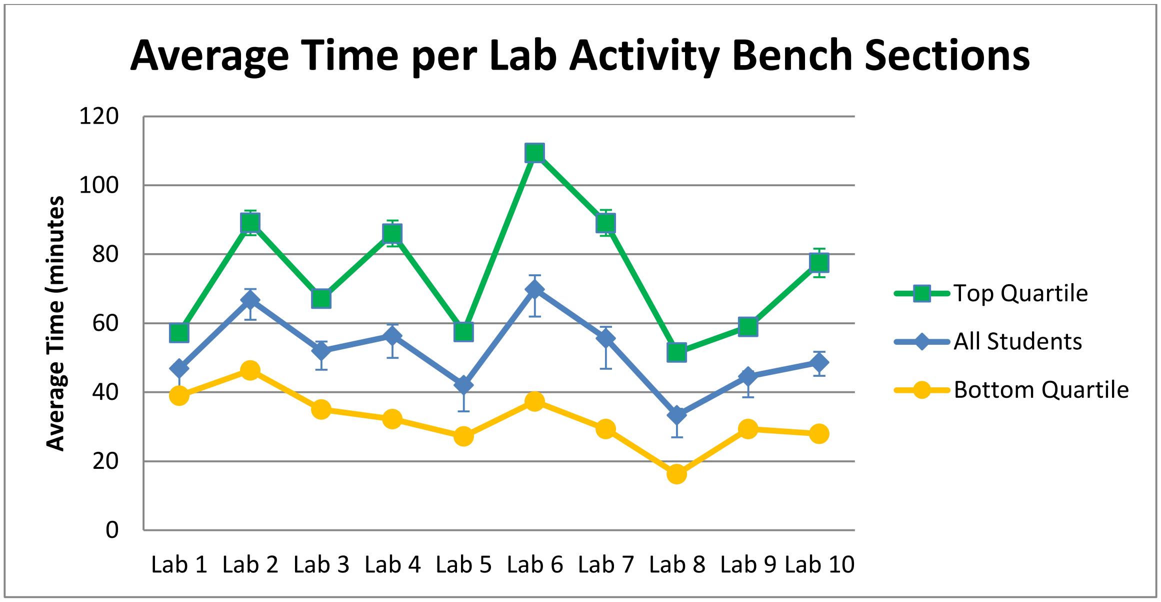


Figure 4.3.3 Average time per Lab Activity in Bench Sections

Figure 4.3.3 above gives a graphical comparison for the average time of all bench lab students and those in the top and bottom quartile of time. The error bars are the standard error. For most of the lab activities the students spending the longest time are spending more than an hour in the lab. The standard lab period is 110 minutes. We can see in Figure 4.3.3 above that for Lab 6 a quarter of students are already spending the entire 110 minutes collecting data and yet there is also a sizeable number of students spending less than 40 minutes. In the majority of labs there are at least a quarter of students spending more than an hour collecting data. Figure 4.3.4 below shows the same comparison using the mean time of students in the bench labs.

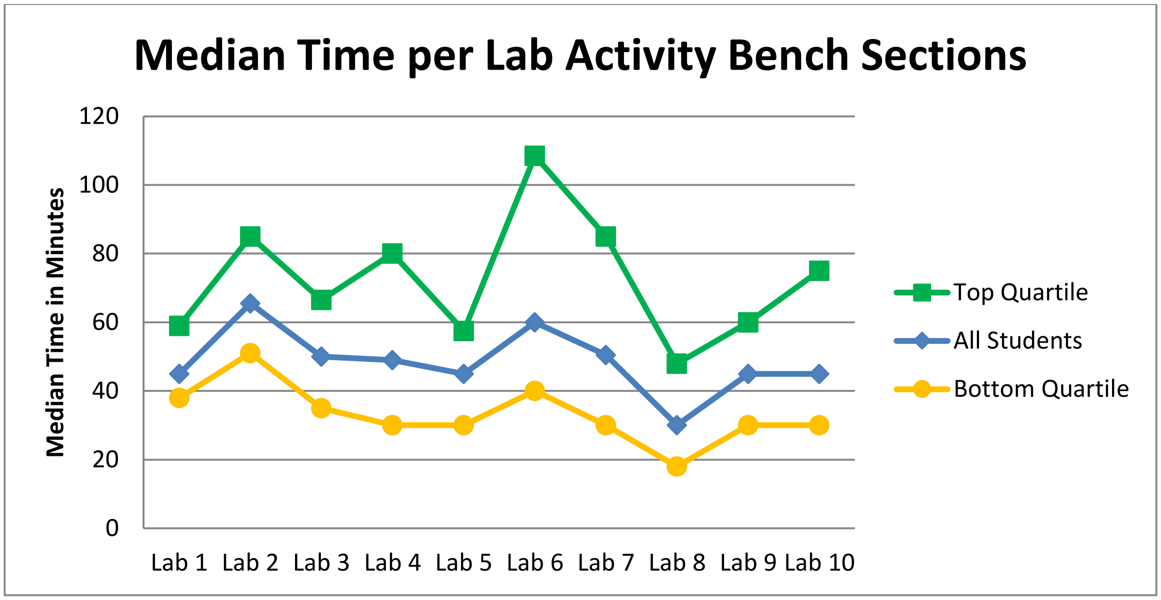


Figure 4.3.4 Median Time per Lab Activity Bench Sections

Again we see a pretty large difference in Figure 4.3.4 above. In this figure we see that that the slower moving students are spending at least an hour on each of the lab activities. Students who complete the labs more quickly are spending typically 40 minutes or less. It is important to not confuse slower moving students with weaker students. In a bench lab situation students are often delayed due to issues with the lab equipment. Among the most common problems is a blown fuse in a multimeter. It is common for students to not know they have blown a fuse on a multimeter. They may continue collecting incorrect data until a lab instructor corrects the error. The result is students are repeating large chucks of the lab they had performed with faulty equipment. The myDAQs have a built in current limiter which prevents this problem. The slower students may just be moving more methodically than other students in the bench lab sections. These tables and figures are intended to show the variation among time spent on labs. Such variations, make it difficult to produce lab activities that are challenging for all students in a traditional lab setting with a fixed 110 minute lab period. The goal of this study is to increase student learning. By removing the time pressure some students are experiencing, it is hoped their learning will increase.

4.4 Discussion

Students, on average, spend more time with the myDAQ than they did the bench labs, see Figures 4.3.1 and 4.3.2. The flexibility of time allocation with the myDAQ is very important for these students. They can work at their own pace without the pressure of the time constraints imposed by working in a typical lab. They can also start and stop. In a bench lab, a student cannot start a lab activity then go off to do something else and come back later. With a myDAQ the student can start or stop the activity whenever they wish. This allows them to return to it and finish at any time. They spend more total time but it may not sequential. Not requiring a long extended time on one task can reduce boredom and decreased interest from a feeling of tediousness. It makes the experience more malleable to the student's preferred style.

There are several possible explanations for why the students in the myDAQ section spent longer than did students in the bench lab sections. One possible explanation is the students struggled more with the myDAQ. Students in the myDAQ labs were given the same basic lecture as students in the bench section. The teaching assistants covered the same theoretical material and then provided examples of common errors to avoid, along with some mistakes to avoid that are specific to use of a myDAQ. Throughout the week there were provided several open lab times where a teaching assistant was in the lab so students using the myDAQ could come in and get help if needed. Students were instructed to include time spent in open labs in their total for the week. Consistently each week only 15-20% of students reported using open lab times.

Struggle is not necessarily a bad thing. With such a low percentage of students using the open lab times, it is most probable that students were able to reason out and solve their problems on their own. This helps develop analytical skills and trouble shooting skills on circuits. As these skills develop, the students will likely develop more confidence in their abilities.

Another possible explanation for the time difference is that students were tinkering with the equipment and developing their own small experiments. However, this was not included in the weekly survey. The myDAQ has a built in current limiter that prevents damage to the device. Students may have spent time testing their own theories and ideas while collecting their data. For example, when building a current divider a student may experiment with having two equal resistors in the current divider or having one much larger than the other just to see what happens. These explorations and test allow students to gain valuable insight into how analog circuits function.

A third possible explanation is that students went slower as they felt less time constraint. Students using the myDAQ were able to do the experiments when they wanted and where they wanted. In a lab, students may feel constrained by a time crunch. They may hurry for fear that they may not finish in time. They may hurry for a reason as spurious as getting done quicker so they can go home, or because they see other groups finishing. A student using the myDAQ knows they do not have to hurry. Alleviating the time concerns may mean students just go slower. Hurried lab work often results in sloppy lab work. In having nearly unlimited time to complete the lab, the student can slow down and move at a pace that is more appropriate to their level of understanding.

It was expected that students would spend longer on the labs using the new pedagogical method. This expectation was bore out. The reason for the time difference is likely due to a combination of all of the above reasons plus a few more.   The new pedagogical method was successful in getting students to spend longer on the lab activities. Student time on task was increased without needing to lengthen the lab activities or length the lab period. The time on task actually increased while shrinking the time in the lab.

4.5 Further study

There are several areas of student time on task that could potentially lead to further study. First among these could be the development of a better manner for measuring student time on task with the myDAQ. Given the high standard deviation for the times reported a good systematic method could be developed for measuring more precisely. One possible way to do this could be through the development of a website that allows students to log their time, or similarly some add on software that would calculate how long the myDAQ was connected to the computer and how long it was used.

There is currently no way to determine if students are developing their own mini experiments. Developing an instrument to measure this would be useful. If, for example, it is found that almost all the students are doing the same thing it could be a regular part of the lab activity. Knowing what exactly the students are doing on their own could provide meaningful insight into what areas the students have difficulty with conceptually. Similarly, there was no measure for time students spent tinkering with the myDAQ.

Another area that would be good for exploration would be to measure student confidence and attitude. As mentioned above, if students are troubleshooting more on their own are they gaining confidence? If the students with the myDAQ are more confident does that confidence equal improved lab skill?

The overall measurement of student time on task has many avenues for future study. In this study time on task was simply used to assess whether the new pedagogical method was impacting student time on task. Knowing more exact measures for how students were spending their time with the myDAQ could lead to curricular changes, such as the introduction of elements of problem based learning through open ended projects. This in turn could help improve the overall learning experience in EE 2010L Circuit Analysis.

5 MANOVA & MANCOVA TESTING

5.1 MANOVA

Significant amounts of data were compared using a multivariate analysis of variance (MANOVA). The experimental design used here resulted in three dependent variables; score on lab practicum midterm exam, score on lab practicum final exam, and Hake's Gain calculated from pre- and post-test scores. The following student characteristics were initially identified as independent variables: major, cumulative GPA, lab type (bench lab section or myDAQ section), lab instructor, and lecture section. Initial assumptions were that these would be largely uncorrelated. The use of MANOVA in EER studies is well established. Numerous studies such as Sageev and Romanowski (2001), Male, Bush, and Murray (2009), and Mansson and Lee (2014) have all utilized MANOVA as part of their work in EER to look for relationships between multiple dependent variables and multiple independent variables.

The use of MANOVA is justified here, as it is expected that the three dependent variables, midterm score, final score, and gain, will have some correlation to one another. Each could be analyzed using a separate ANOVA, however, doing this could lead to an increase in a Type I error. The separate ANOVA test would also not show interactions among the independent variables. As noted by Grice and Iwasaki (2007), "the conceptual meaning of the results of a series of ANOVAs will not necessarily match the conceptual meaning of the results from a MANOVA". Despite the differences in results, MANOVA is still run on the same assumptions as ANOVA. These assumptions (French, Poulsen, & Yu, 2002) are normal distribution, linearity, homogeneity of variances, and homogeneity of variances and covariances. MANOVA is a particularly useful tool in dealing with data that is not continuous and is collected as textual data as opposed to numeric data (Wold, 2009).

To perform MANOVA testing the collected data must be coded. This means that text data must be translated in to a numeric code in order to perform calculations. Table 5.1.1 below shows the code.

Coding Values								
Lab	01	02	03	04	05	06	07	08
	-4	-3	-2	-1	1	2	3	4
GPA	1.50-1.99	2.00-2.49	2.50-2.99	3.00-3.49	3.50-4.0			
	-2	-1	0	1	2			
TA	Alpha	Foxtrot	Delta	Echo	Bravo			
	-2	-1	0	1	2			
Major	ME/MAT	Other	CEG/CS	EE/EP				
	-2	-1	1	2				
Lecture	01	02	03					
	-1	0	1					
Lab Type	Bench	MyDAQ						
	-1	1						

Table 5.1.1 Coding Values for Data

The majors were grouped together by sponsoring department. This is why Mechanical Engineering is combined with Materials Science, and Engineering Physics is combined with Electrical Engineering. Academic majors in the same department typically enter EE 2010L Circuit Analysis with very similar background preparation and at similar points in their undergraduate career. GPA represents the students cumulative GPA. This was broken into half point increments. There were three lecture sections and they were simply coded by section number. There were two lab types and they were coded thusly. The lab sections were taught by teaching assistants (TAs). Each TA was assigned a letter of the phonetic alphabet to protect their privacy. These were encoded as shown above. Coding was selected so that it would be as close to orthogonal as possible.

5.2 MANOVA Assumption Testing

In order to run MANOVA, the data was tested against these assumptions to ensure valid conclusions could be drawn. First it was determined if the data had a normal distribution. A normal distribution is necessary as outliers in the data can greatly increase the incident of Type I and Type II errors. Further complicating matters such outliers can mean we cannot distinguish between which type of error is occurring, Type I or Type II. A simple t-test was done to determine if there were outliers for the identified independent variables. Mean and standard deviation were found. From this, a value was determined. A t of 1.9506 was used. This t was multiplied by the standard deviation to produce an outlier rejection criterion. Based on this criterion there were no outliers found. The complete table can be found in appendix A. It is not included here because it is quite large with six independent variables for 125 students.

To establish the homogeneity of variance we need to calculate the error variance. This was accomplished by calculating the within group variation for each of the identified independent variables. The variance was calculated by dividing the sum of squares by the N-1 where N is the number of trials. The exact equation is shown below:

$$varaince = \frac{\sum(x_i - \bar{x})^2}{N - 1}$$

Variance was calculated for each of the identified independent variables. The data should be pooled from equal sets and the variance in each should be the same in order to proceed with the MANOVA analysis.

	Variance in Independent Variables					
	Lab Type	TA	Lab	Lecture	GPA	Major
SumSq	125	360	941	77	211	455
Count	125	125	125	124	125	125
Varaince	1.004024	1.703886	2.754761	0.791212	1.304459	1.915556

Table 5.2.1 Variance in the Independent Variables

Table 5.2.1 shows the variance found for each of the independent variables. The variance for the lab section is clearly much different from the others. After a reconsideration of the data this information is already encoded based on the TA and Lab Type. Thus, the lab column, listing lab section, is redundant and can be removed from consideration.

Additionally, a way to account for change in students test scores from pre-test to post-test needs to be considered. Hake's Gain will be calculated and used for this purpose (Hake 1998). This measure takes into account not only how much did a student improve from the pre-test to the post-test, but also how much room for improvement was there. One of the difficulties in working with pre-test and post-test scores is that high performing students may not show as much improvement if they score better on the initial pre-test. Hake's Gain, G, is calculated using the following equation

$$G = \frac{Post\ Score - Pre\ Score}{Max\ Possible - Pre\ Score}$$

Post score is the post-test score and pre score is the pre-test score. Max Possible is the maximum score possible on the assessment.

5.3 MANOVA Results

The MANOVA results were found using the *Minitab* software package. A general linear model MANOVA was performed. In the calculations, lecture section was used as a covariate. It was treated as a covariate and not an independent variable as the students major may have strong impact upon which lecture sections students enrolled. Table 5.3.1 below shows the result of the MANOVA analysis.

MANOVA Results					
MANOVA for Lecture					
s=1	m=0.5	n=50.0			
	Test		DF		
Criterion	Statistic	F	Num	Denom	P
Wilks'	0.99000	0.343	3	102	0.794
Lawley-Hotelling	0.01010	0.343	3	102	0.794
Pillai's	0.10000	0.343	3	102	0.794
Roy's	0.01010				
MANOVA for TA					
s=3	m=0.0	n=50.0			
	Test		DF		
Criterion	Statistic	Approx F	Num	Denom	P
Wilks'	0.88068	1.108	12	270	0.354
Lawley-Hotelling	0.13206	1.108	12	302	0.353
Pillai's	0.12234	1.105	12	312	0.355
Roy's	0.09738				
MANOVA for Lab Type					
s=1	m=0.5	n=50.0			
	Test		DF		
Criterion		Approx	Num	Denom	P

	Statistic	F			
Wilks'	0.99380	0.212	3	102	0.888
Lawley-Hotelling	0.00624	0.212	3	102	0.888
Pillai's	0.00620	0.212	3	102	0.888
Roy's	0.00624				
MANOVA for GPA					
s=3	m=0.0	n=50.0			
	Test		DF		
Criterion	Statistic	Approx F	Num	Denom	P
Wilks'	0.67597	3.592	12	270	0.000
Lawley-Hotelling	0.44485	3.732	12	302	0.000
Pillai's	0.34776	3.409	12	312	0.000
Roy's	0.35378				
MANOVA for Major					
s=3	m=-0.5	n=50.0			
	Test		DF		
Criterion	Statistic	Approx F	Num	Denom	P
Wilks'	0.93365	0.79	9	248	0.626
Lawley-Hotelling	0.07024	0.786	9	302	0.630
Pillai's	0.06713	0.793	9	312	0.623
Roy's	0.05546				

Table 5.3.1 MANOVA Results

The first values are for giving context to the sample under study. The s value is the standard error, and m is the population mean. The table above gives several statistics. There are five given test statistics, Wilks' Lambda, Lawley-Hotelling T^2, Pillai's Trace, and Roy's Largest Root. All five give measures of the amount of variance in the data. The statistic of most interest is the p-value. This is the standard p-value. It is a measure of the probability that the result would be obtained from standard error. At a 95% confidence level we would only say factors having a p-value of 0.05 or less are statistically significant. If we look at the above table, we see that only GPA has p-values below this threshold. Since the listed p-value for GPA is below 0.001 we can say there is a strong correlation between GPA and scores on the midterm lab practicum, the final lab practicum, and the change in score from pre-test to post-test.

We can also infer from the remaining p-values that none of the other dependent variables, TA, Lab Type, Major, nor the covariate of Lecture are significant factors affecting the students performance on the identified independent variables. At this stage of data analysis it appears that the only statistically significant factor is GPA. To get further insight we will next consider an analysis of covariance.

5.4 ANCOVA and MANCOVA

ANCOVA is the univariate analysis of covariance, and MANCOVA is the multivariate analysis of covariance. These methods are often thought of as being in the middle of regression analysis and analysis of variation. These methods use both continuous variables and discrete variables. In the analysis here, the GPA will be used as the actual student GPA and not the scaled coded values used in the MANOVA analysis. Major, TA, and Lab Type will continue to be used in the coded values as they were in the MANOVA analysis. It is the ability to handle continuous with non-continuous data that produces an extra layer of detail about the data.

An analysis was done again using *Minitab* software. The results are run using a General Linear Model of analysis under the statistics menu. As GPA is continuous, it was used as the covariate while Major, TA, and Lab Type were used as the model. Lecture was removed from consideration here. Table 5.4.1 shows the results from this analysis.

MANCOVA Analysis						
Analysis of Variance for Midterm, using Adjusted SS for Tests						
Source	DF	Seq SS	Adj SS	Adj MS	F	P
GPA	1	1567.9	1277.5	1277.5	6.42	0.013
Major	3	359.9	360.0	120.0	0.60	0.614
TA	4	589.7	623.6	155.9	0.78	0.538
Lab Type	1	72.1	72.1	72.1	0.36	0.548
Error	108	21488.8	21488.8	199		
Total	117	24078.4				
S=14.1057		R-Sq= 10.75%		R-Sq (adj) = 3.32%		
Term	Coef	SE Coef	T	P		
Constant	92.212	2.542	36.28	0.000		
GPA	2.904	1.146	2.53	0.013		
Analysis of Variance for Final, using Adjusted SS for Tests						
Source	DF	Seq SS	Adj SS	Adj MS	F	P
GPA	1	9352.9	10083.4	10083.4	14.16	0.000
Major	3	728.4	765.0	255.0	0.36	0.783
TA	4	4200.3	3646.0	911.5	1.28	0.282
Lab Type	1	1.4	1.4	1.4	0.00	0.965
Error	108	76916.3	76916.3	717.0		
Total	117	91199.4				
S=26.6869		R-Sq= 15.66%		R-Sq (adj) = 8.63%		
Term	Coef	SE Coef	T	P		
Constant	171.7367	4.808	25.72	0.000		
GPA	8.159	2.168	3.76	0.000		
Analysis of Variance for Gain, using Adjusted SS for Tests						

Source	DF	Seq SS	Adj SS	Adj MS	F	P
GPA	1	2.495	1.967	1.967	11.60	0.001
Major	3	0.293	0.438	0.146	0.86	0.463
TA	4	0.850	0.797	0.199	1.18	0.326
Lab Type	1	0.001	0.001	0.001	0.01	0.934
Error	108	18.308	18.308	137.800		
Total	117	21.946				
S=0.411723		R-Sq= 16.58%		R-Sq (adj) = 9.63%		
Term	Coef	SE Coef	T	P		
Constant	0.31198	0.07418	4.21	0.000		
GPA	-0.11395	0.03345	-3.41	0.001		

Table 5.4.1 MANCOVA Analysis

In Table 5.4.1 there are two types of data given. The first part is the significance of each variable on the outcome. Again we will look at the p-values. Just as in the MANOVA analysis, we see that GPA is the only variable which is statistically significant. The second part of the data shows the regression fit. Again the p-value shows that the GPA is statistically significant. The regression equations would be the following:

$$Midterm = 2.904GPA + 92.212$$

$$Final = 8.159GPA + 171.767$$

$$Test\ Change = -0.11395GPA + 0.31198$$

Shown below are the plots for the regressions.

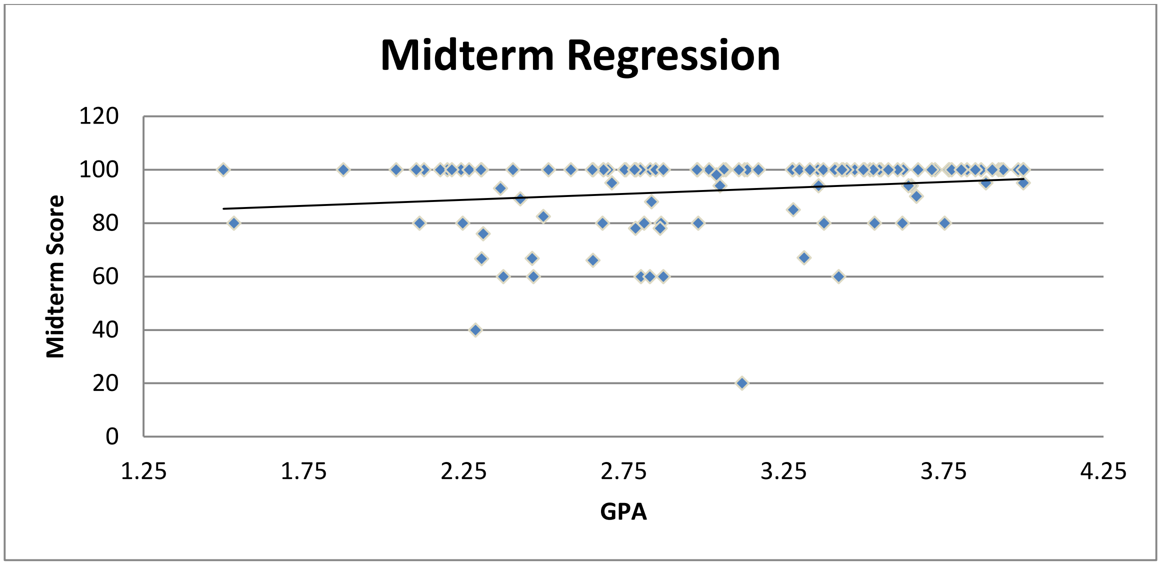


Figure 5.4.1 Midterm Score Regression

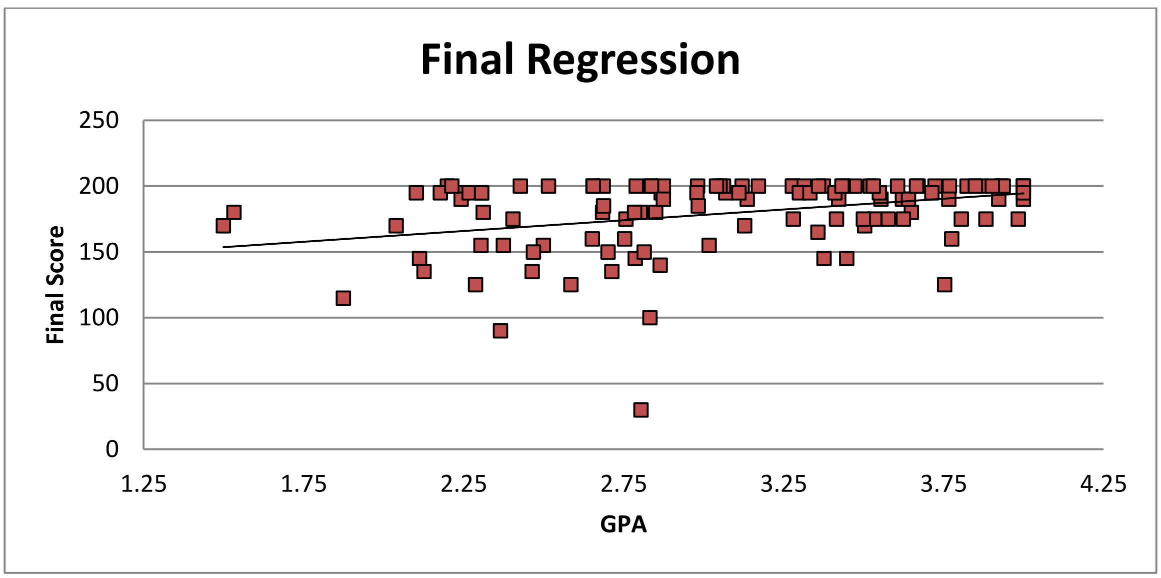


Figure 5.4.2 Final Score Regression

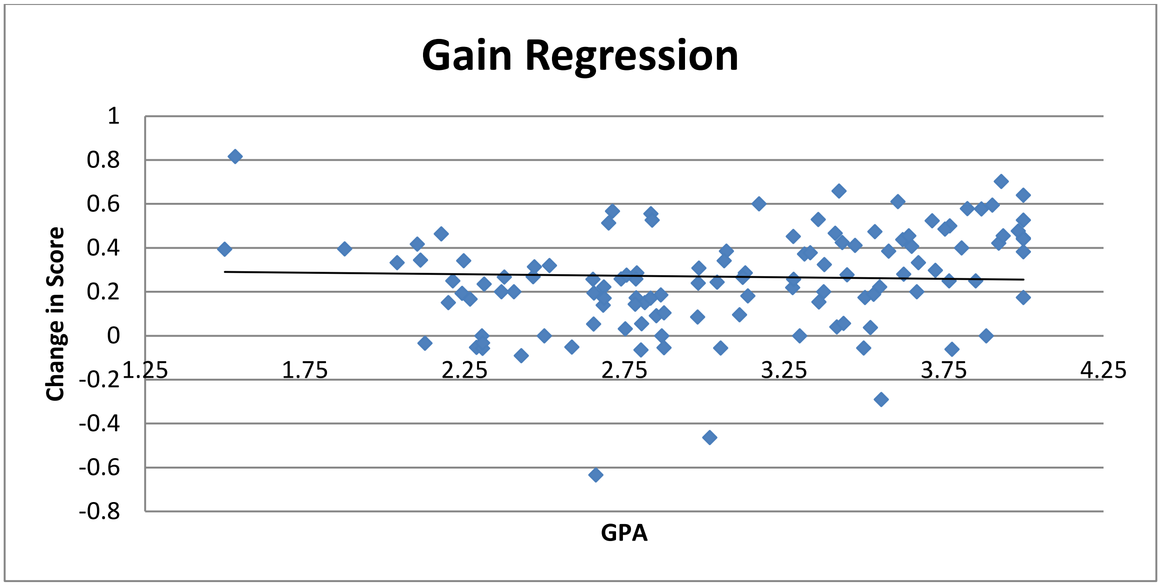


Figure 5.4.3 Gain Regression

The regression values for the Gain are unexpected. The regression trend line has a negative slope and is much smaller than the slope of the other regression plots. This may be caused by outliers. The mean of the gain and standard deviation of the gain values were found. Table 5.4.2 shows the values

Central Tendency of Gain			
Mean	Stdev (σ)	Mean+2σ	Mean-2σ
0.428315	0.194128	1.050759	-0.6625

Table 5.4.2 Mean and Standard Deviation of Gain

Data more than two standard deviations from the mean was considered an outlier and removed. Once the outliers were removed a linear regression was performed again. Table 5.4.3 shows the results of this regression and Figure 5.4.4 shows the graphical results.

Modified Gain Regression					
Modified Gain Regression					
Regression Statistics					
Multiple R	0.229164985				
R Square	0.05251659				
Adjusted R Square	0.044205332				
Standard Error	0.317687688				
Observations	116				
ANOVA					
	df	*SS*	*MS*	*F*	*Sig F*
Regression	1	0.637721	0.637721	6.318729	0.013343
Residual	114	11.5055	0.100925		
Total	115	12.14322			
	Coefficients	Std Error	t Stat	P-value	
Intercept	0.62353382	0.150439	4.144753	6.56E-05	
X Variable 1	-0.12259437	0.04877	-2.51371	0.013343	

Table 5.4.3 Modified Gain Regression

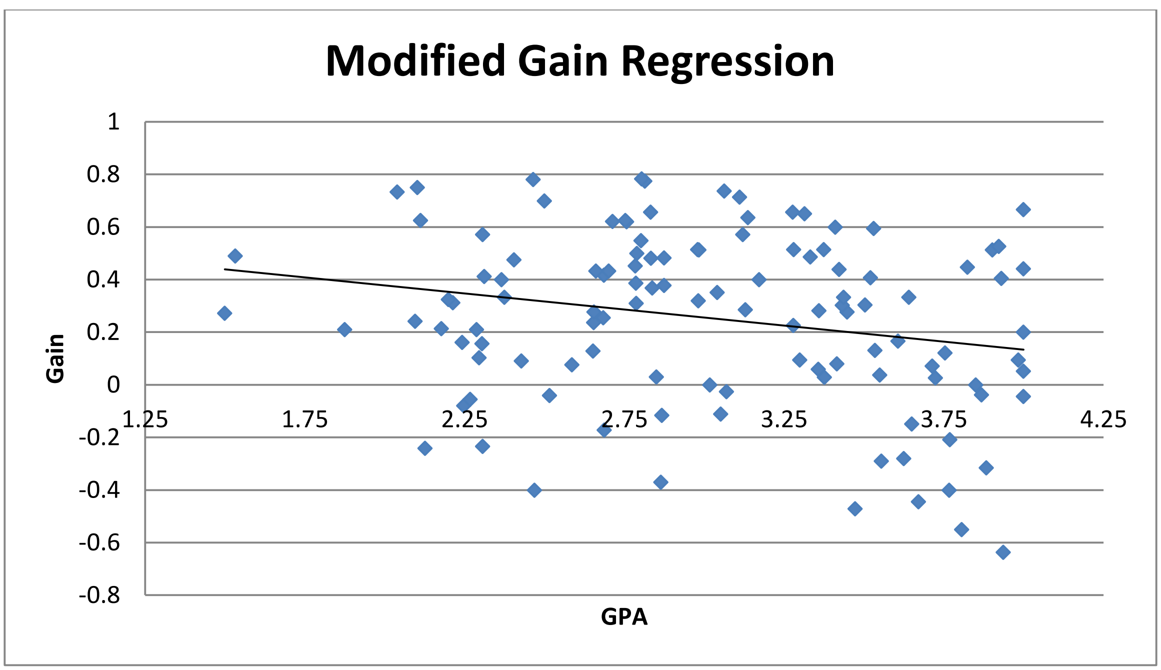


Figure 5.4.4 Modified Gain Regression

Again we find a small negative slope to the regression. The p values indicate there is statistical significance. The small slope value indicates that there is a weak correlation between gain and GPA.

5.5 Additional Post Hoc Testing

An additional post-hoc test was performed to gain some more insight into interactions among variables. Pearson's correlation coefficient r was calculated for the dependent variables. It gives us a descriptive value of the linear correlation between two values. It is a useful tool when dealing with categorical multivariate data (Jarneving & Rousseau, 2003). The r coefficient is useful in that it is normalized and has a finite size range, -1 to 1 (Egghe & Leydesdorff, 2009). Table 5.5.1 below shows the calculated Pearson's correlation coefficient r values.

Pearson's Correlation r	
GPA	
Midterm	0.250133316
Final	0.357789218
Gain	-0.10310064
Lab type	
Midterm	7.50415E-06
Final	0.00023672
Gain	-0.05323596
Major	
Midterm	-0.01891632
Final	0.005073096
Gain	0.142600831
TA	
Midterm	-0.12814406
Final	-0.03456187
Gain	0.000446413

Table 5.5.1 Pearson's Correlation Coefficient r Values

The magnitude, absolute value, of r tells us the strength of the correlation. Using the scale described in Cicchetti et. al. (2011), r values can be categorized as: "<0.10 = Trivial; 0.10 = Small; 0.30 = Medium; and >0.50 = Large." This table provides us with some new insight. We know from previous analysis that GPA was significant. But we now know that it only has a small correlation to Gain. This helps explain why the regression for Gain had such a small slope and was negative. We also see that TA had a very small correlation to the score on the midterm exam. There is also a small correlation between Major and Gain.

Based on the results of the Pearson's correlation coefficient an ANOVA was performed for Midterm vs TA. Additionally, a second ANOVA was performed for Gain vs Major. The ANOVA results of which are shown in Table 5.5.2 below.

Analysis of Varaince for Midterm						
Source	DF	Seq SS	Adj SS	Adj MS	F	P
TA	4	889.3	889.3	222.3	1.08	0.368
Error	113	23189.1	23189.1	205.2		
Total	117	24078.4				
s=14.3253		R-Sq=3.69%		R-Sq(adj)=0.28%		

Analysis of Varaince for Gain						
Source	DF	Seq SS	Adj SS	Adj MS	F	P
TA	4	0.3807	0.3807	0.1269	0.67	0.572
Error	113	21.5657	21.5657	0.1892		
Total	117	21.9464				
s=0.434940		R-Sq=1.73%		R-Sq(adj)=0.00%		

Table 5.5.2 ANOVA Results for Midterm vs TA and Gain vs Major

A general linear model was run in for both analyses. In the first, Midterm score was used as the response and TA as the model. In the second, Gain was used as the response and

Major as the model. Both analyses produced p values that would lead to the conclusion they are not statistically significant. They both have a very weak correlation but further testing has shown that TA was not a significant factor for the score on the midterm lab practicum. Likewise, a student's major was not a statistically significant factor in the result gain on the ECCE exam.

A paired t-test was also performed. Students in the same major were paired based upon GPA. The overall course group was divided by major into four groups. The four groups were students majoring in Computer Engineering & Computer Science, students majoring in Electrical Engineering & Engineering Physics, students majoring in Mechanical Engineering & Materials Science, and students majoring in everything else. The low enrollment numbers of the first and last group would have produced a limited number of pairs so these groups were excluded. The remaining two groups were divided between treatment and control groups. Pairs were made between treatment and control groups using GPA. Pairings were made so that the GPA was as close as possible, with a maximum difference of 0.3 between the two. In a standard grading scale with plus and minus grades (A=4, A-=3.7, B+=3.3, B=3.0, B-=2.7, ….) the difference between grades is 0.3. So for this study, grades that are within 0.3 of each other were assumed to be the same. Data points without a pair match were excluded.

This resulted in 17 pairs of Electrical Engineering majors and 26 pairs of Mechanical Engineering majors. The basic descriptive statistics of the pairs is shown below in Table 5.5.3

		Electrical Majors						
		Midterm		Final		Test Change		
	n	Mean	Stdev	Mean	Stdev	Mean	Median	Stdev
Bench	17	93.1767	11.1649	182.647	23.7906	14.0588	13	11.0650
MyDAQ	17	91.7647	21.2824	177.353	30.1619	7.52941	10	8.17096
		Mechanical Majors						
		Midterm		Final		Test Change		
	n	Mean	Stdev	Mean	Stdev	Mean	Median	Stdev
Bench	26	91.9342	11.6107	177.885	21.7335	7.38462	7	5.35968
MyDAQ	26	93.4077	13.8991	184.808	34.2777	6.23077	6.5	6.23077

Table 5.5.3 Descriptive Statistics for Paired t-Test

There are only 17 pairs for Electrical Engineering majors. This number is fairly low and if we look at the standard deviation values we see that there is a big difference for the standard deviation for the midterm and change in test score for the Electrical Engineering majors. Given the small sample size these may be heavily impacted by the presence of outliers. Corrections for such outliers would result in an even smaller number of pairs. Due to this low sample size, electrical engineering pairs are eliminated from further consideration. The 26 pairs produced from Mechanical Engineering majors is low, but there does not appear to be any outliers disrupting the data.

A series of paired t-tests were performed on the pairs of students majoring in Mechanical Engineering. T-tests were conducted for the score on the lab practicum midterm grade, lab practicum final grade, and the change in score from pre-test to post-test. The results are shown below in Table 5.5.4.

Mechanical Engineering Majors t-Test: Paired Two Sample for Means						
	Midterm		Final		Test change	
	Bench	*myDAQ*	*Bench*	*myDAQ*	*Bench*	*myDAQ*
Mean	91.9346	93.4077	177.885	184.808	7.384615	6.230769
Variance	134.807	193.186	472.3462	1174.96	28.72615	39.94462
Observations	26	26	26	26	26	26
Pearson Correlation	0.30418		-0.00728		-0.21055	
Hypoth Mean Diff	0		0		0	
df	25		25		25	
t Stat	- 0.49547		-0.86691		0.64605	
P(T<=t) one-tail	0.31230		0.19712		0.26207	
t Critical one-tail	1.70814		1.70814		1.70814	
P(T<=t) two-tail	0.62459		0.39424		0.52414	
t Critical two-tail	2.05954		2.05954		2.05954	

Table 5.5.4 t-Test: Paired Two Sample for Means for Mechanical Engineering Majors

Again looking at the p values we see they are all above 0.05, meaning there was no statistical significance to the control group or treatment group. This serves to reinforce the results of MANOVA analysis, that the type of lab section a student was in did not impact the student learning outcomes.

A paired t-test was also performed between pre-test and post-test scores. For this comparison, the pre-test score was paired with the post-test score for the same student. The results are shown below in Table 5.5.5.

Pre-test & Post-test t-Test: Paired Two Sample for Means		
	Pre	*Post*
Mean	17.50833	25.925
Variance	59.41169	74.55735
Observations	120	120
Pearson Correlation	0.576963	
Hypoth Mean Diff	0	
df	119	
t Stat	-12.1941	
P(T<=t) one-tail	5.46E-23	
t Critical one-tail	1.657759	
P(T<=t) two-tail	1.09E-22	
t Critical two-tail	1.9801	

Table 5.5.5 Pre-Test & Post-Test t-Test: Paired two Sample for Mean

We see in Table 5.5.5 that the p values are very near zero. This indicates that there is a very strong relationship between the two tests, meaning that a student's score on the post-test was very much tied to their score on the pre-test. This would be expected, and the t-test serves of confirmation of that expectation.

5.6 Discussion & Further Study

Both the MANOVA and MANCOVA analysis indicate that the only statistically significant factor affecting student performance in EE 2010L was their GPA. The TA, the lecture section, and the students' major did not make a difference. Most importantly, there was no difference between students in the treatment group (myDAQ labs) and students in the control group (bench labs). This result was further supported by the paired t-test results between students majoring in Mechanical Engineering. The t-test showed that the difference between scores for students in the control group and students in the treatment group was not statistically significant. It should generally be expected that GPA would be statistically significant. GPA is a measure of the students' academic achievement prior to entering the course. As such, one would naturally assume that students' academic performance in the course would be in line with prior academic achievement. The negative regression slope for the gain was unexpected. However, the slope is quite small and could simply mean there is little correlation between the two. A t-test comparison between the pre-test scores and post-test scores confirmed they were linked, as expected. P value scores in the test were very small (nearly zero). It is expected that scores on the pre-test would be linked to scores on the post-test. However, in the data we see points where the post-test score was less than the pre-test score. Such data could indicate a flaw in the experimental design. The paired t-test between pre-test and post-test scores was done to confirm that the expected link between scores was indeed present. As they are linked we can conclude the data points where the score decreased are likely outliers.

Perhaps the most obvious aspect which could be looked at in future studies is the sample size. The overall sample size was rather modest at 122. There are 125 data points listed in the data table, but only 122 have pre-test, post-test, lab practicum midterm score, and lab practicum final score. The sample sizes for the treatment and control group were both small, at 56 and 66 respectively. Larger sample sizes would allow for paired t-test comparisons between more majors. Collecting the data on a larger scale would reduce variational errors and likely bring effects into a sharper contrast.

6 Descriptive Analysis

6.1 Demographics of Groups

When making comparisons it is important to consider the types of groups being compared. Most often we want these groups to be as similar as possible in terms of composition. The primary concern of this study is to compare the results of students in a traditional lab setting and those in a lab using an inverted pedagogical setting. Table 6.1.1 shows a brief demographic breakdown of the students enrolled in EE 2010L in Spring Semester 2014.

	Demographic Makeup of Spring 14 Cohorts						
	GPA			Major			
	Mean	Median	Stdev	EE/EP	ME/MAT	CEG/CS	Other
Bench	3.049	3.061	0.615	25.8%	63.6%	9.1%	3.0%
MyDAQ	3.044	3.018	0.609	35.6%	50.8%	10.2%	3.4%

Table 6.1.1 Demographic Makeup of Spring 14 Cohort

We can see in Table 6.1.1 that the two groups are comparable to one another. The students in the bench lab and the students in the myDAQ lab sections have nearly identical GPA measures. The breakdown of students by major for the two groups is relatively similar. Both groups have the majority of students majoring in Mechanical Engineering programs. There is a large group majoring in Electrical Engineering Programs with a small number majoring in Computer Engineering and about 3% majoring in other fields.

6.2 Student Performance

Given that the two groups have equal composition we can use simple descriptive statistics to look to reaffirm the results found using MANOVA and MANCOVA analysis.

Table 6.2.1 shows student performance on the lab practicum midterm based on major. Table 6.2.2 shows student performance on the lab practicum final based on major. Table 6.2.3 shows gain by major.

	Midterm Results by Major							
	EE/EP		ME/MAT		CEG/CS		All	
	Bench	MyDAQ	Bench	MyDAQ	Bench	MyDAQ	Bench	MyDAQ
Mean	93.176	87.952	90.769	93.287	96.667	96.667	91.959	91.959
Median	100	100	100	100	100	100	100	100
Stdev	11.165	25.339	14.067	13.216	8.165	8.165	12.806	18.048
Count	17	21	42	30	6	6	66	59

Table 6.2.1 Midterm Lab Practicum Results by Major

	Final Results by Major							
	EE/EP		ME/MAT		CEG/CS		All	
	Bench	MyDAQ	Bench	MyDAQ	Bench	MyDAQ	Bench	MyDAQ
Mean	182.647	176.000	173.929	185.370	176.667	185.000	175.152	181.316
Median	195	192.5	187.5	195	185	187.5	190	195
Stdev	23.791	30.591	33.231	33.739	23.381	10.954	31.707	30.112
Count	17	20	42	29	6	6	66	57

Table 6.2.2 Final Lab Practicum Results by Major

	Gain by Major							
	EE/EP		ME/MAT		CEG/CS		All	
	Bench	MyDAQ	Bench	MyDAQ	Bench	MyDAQ	Bench	MyDAQ
Mean	0.406	0.216	0.218	0.208	0.331	0.373	0.277	0.232
Median	0.400	0.272	0.250	0.222	0.411	0.364	0.258	0.254
Stdev	0.244	0.244	0.226	0.199	0.228	0.134	0.241	0.214
Count	17	20	41	29	6	6	65	56

Table 6.2.3 Gain by Major

From Table 6.2.1, Table 6.2.2, and Table 6.2.3 we can see there are no patterns and no correlations between major and outcome. No major did noticeably better or worse than the other majors. The midterm lab practicum results are fairly consistent across all majors. In fact all majors had the same median score on the lab practicum midterm. When we break down these results between bench and myDAQ labs within major, we see no discernible difference as well. Likewise, for final lab practicum, we see values are relatively close with no clear pattern as to which lab type performed better. We can do a similar analysis of the scores broken down by GPA.

	Midterm							
	<2.50		2.51-3.00		3.01-3.50		3.501-4.00	
	Bench	MyDAQ	Bench	MyDAQ	Bench	MyDAQ	Bench	MyDAQ
Mean	84.320	86.967	91.971	89.235	93.786	91.786	96.400	98.750
Median	100	100	100	100	100	100	100	100
Stdev	18.048	25.381	11.893	15.246	11.623	22.444	6.336	5.000
Count	15	12	17	17	14	14	20	16

Table 6.2.4 Lab Practicum Midterm Score by GPA

	Final							
	<2.50		2.51-3.00		3.01-3.50		3.501-4.00	
	Bench	MyDAQ	Bench	MyDAQ	Bench	MyDAQ	Bench	MyDAQ
Mean	156.000	183.500	163.235	169.118	188.571	182.857	190.500	187.500
Median	190	182.5	160	180	190	195	195	197.5
Stdev	34.341	16.338	41.644	45.970	11.339	24.076	11.110	20.494
Count	15	10	17	17	14	14	20	16

Table 6.2.5 Lab Practicum Final Score by GPA

	Gain by GPA							
	<2.50		2.51-3.00		3.01-3.50		3.501-4.00	
	Bench	MyDAQ	Bench	MyDAQ	Bench	MyDAQ	Bench	MyDAQ
Mean	0.207	0.238	0.167	0.179	0.315	0.188	0.391	0.322
Median	0.235	0.257	0.178	0.172	0.351	0.254	0.404	0.431
Stdev	0.232	0.181	0.280	0.156	0.217	0.238	0.181	0.248
Count	15	10	16	16	14	14	20	16

Table 6.2.6 Gain by GPA

Table 6.2.5, Table 6.2.5, and Table 6.2.6 above show the score breakdown based on GPA groupings. In these tables we see that the scores get progressively higher as GPA gets higher. As the results from MANOVA and MANCOVA stated, the GPA was statistically significant and we see this in the basic descriptive statistics.

6.3 Comparison with Prior Term Results

As mentioned previously the same lab activities, lab practicum midterm, and same lab practicum final were given to students in the Fall Semester of 2013. The pre-test and post-test were not administered during the Fall Semester. A small cohort of 8 students used the myDAQs in the Fall while the rest of the students used the traditional bench lab equipment. One other important difference is that in the Fall Semester students performed the lab practica on the same equipment they used in the lab week over the course of the semester. The equipment used was:

- Tenma 72-1020 Digital Multimeter
- Agilent E36314 Triple Output DC power Supply
- HP 54600B Oscilloscope
- HP 33120A 15MHz Arbitrary Waveform Generator

A comparison between students in Fall Semester and students in Spring Semester would be useful.

When considering the demographics we will see a pattern similar to what was observed in the Spring Semester. Table 6.3.1 below shows the demographics.

	Demographic Makeup of Test Groups						
	GPA			Major			
	Mean	Median	Stdev	EE/EP	ME/MAT	CEG/CS	Other
Fall 13	2.775	2.767	0.566	31.7%	52.4%	11.9%	4.0%
Bench	3.049	3.061	0.615	25.8%	63.6%	9.1%	3.0%
MyDAQ	3.044	3.018	0.609	35.6%	50.8%	10.2%	3.4%

Table 6.3.1 Demographic Makeup of Test Groups in Fall and Spring

Table 6.3.1 divides the students into three test groups. Bench lab students from the Fall Semester (labeled as “Fall 13”), students in the control bench lab groups in Spring Semester (labeled as “Bench”), and students in the treatment group in Spring Semester (labeled as “MyDAQ”). The percentage of students in each major is comparable between the three groups. The mean and median GPA values for Fall 13 are slightly below those of the bench and myDAQ groups. Using the standard deviation as the error they are all within range of one another and can be compared directly.

		Midterm			
		Mean	Median	Stdev	Count
EE/EP	Fall 13	71.350	82	31.285	40
	Bench	93.176	100	11.165	17
	MyDAQ	87.952	100	25.339	21
ME/MAT	Fall 13	78.121	82	25.171	66
	Bench	90.769	100	14.067	42
	MyDAQ	93.287	100	13.216	30
CEG/CS	Fall 13	77.467	84	24.962	15
	Bench	96.667	100	8.165	6
	MyDAQ	96.667	100	8.165	6
All	Fall 13	75.810	82	27.253	126
	Bench	91.959	100	12.806	66
	MyDAQ	91.959	100	18.048	59

Table 6.3.2 Midterm Score by Major

		Final			
		Mean	Median	Stdev	Count
EE/EP	Fall 13	145.725	179.5	68.259	40
	Bench	182.647	195	23.791	17
	MyDAQ	176.000	192.5	30.591	20
ME/MAT	Fall 13	162.606	175	47.539	66
	Bench	173.929	187.5	33.231	42
	MyDAQ	185.370	195	33.739	29
CEG/CS	Fall 13	169.933	185	35.917	15
	Bench	176.667	185	23.381	6
	MyDAQ	185.000	187.5	10.954	6
All	Fall 13	157.881	177	54.426	126
	Bench	175.152	190	31.707	66
	MyDAQ	181.316	195	30.112	57

Table 6.3.3 Lab Practicum Final Scores by Major

Table 6.3.2 and Table 6.3.3 show that with the Fall 13 data the students major did not have an impact upon their score on the lab practicum midterm or lab practicum final. However, it should be noted that the scores for Fall 13 are below those of both the bench and myDAQ groups. Possible reasons for this will be discussed in a later section.

We can produce similar tables that include the data from Fall 13 delineating by GPA. Table 6.3.4 below shows this for the lab practicum midterm, and Table 6.3.5 shows this for the lab practicum final.

		Midterm			
		Mean	Median	Stdev	Count
<2.50	Fall 13	62.087	72	33.323	46
	Bench	84.320	100	18.048	15
	MyDAQ	86.967	100	25.381	12
2.51-3.00	Fall 13	78.650	82	20.373	40
	Bench	91.971	100	11.893	17
	MyDAQ	89.235	100	15.246	17
3.01-3.50	Fall 13	87.385	92	19.356	26
	Bench	93.786	100	11.623	14
	MyDAQ	91.786	100	22.444	14
3.501-4.00	Fall 13	91.286	97	10.745	14
	Bench	96.400	100	6.336	20
	MyDAQ	98.750	100	5.000	16

Table 6.3.4 Lab Practicum Midterm Score by GPA

		Final			
		Mean	Median	Stdev	Count
<2.50	Fall 13	130.370	147.5	69.694	46
	Bench	156.000	190	34.341	15
	MyDAQ	183.500	182.5	16.338	10
2.51-3.00	Fall 13	170.050	182.5	36.128	40
	Bench	163.235	160	41.644	17
	MyDAQ	169.118	180	45.970	17
3.01-3.50	Fall 13	171.500	179.5	39.559	26
	Bench	188.571	190	11.339	14
	MyDAQ	182.857	195	24.076	14
3.501-4.00	Fall 13	188.214	192.5	15.764	14
	Bench	190.500	195	11.110	20
	MyDAQ	187.500	197.5	20.494	16

Table 6.3.5 Lab Practicum Final Score by GPA

We can see in the above tables that for all three groups the scores improve with the GPA. We can also see that the scores for the Bench and MyDAQ cohort are higher than those of the Fall 13 cohort. Figure 6.3.1 and Figure 6.3.2 show the mean scores graphically for easier comparison.

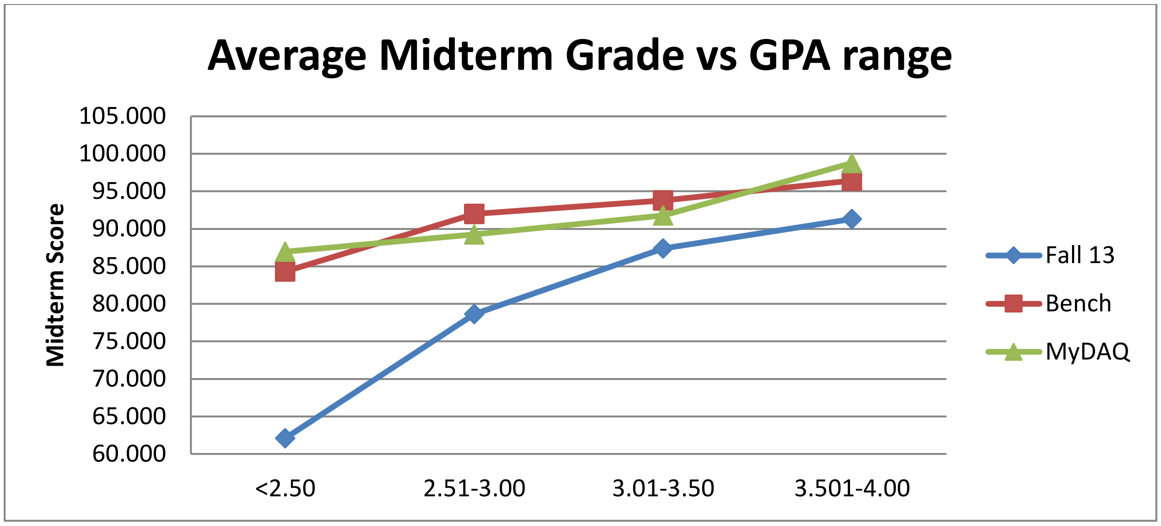


Figure 6.3.1 Average Lab Practicum Midterm Grade vs GPA range

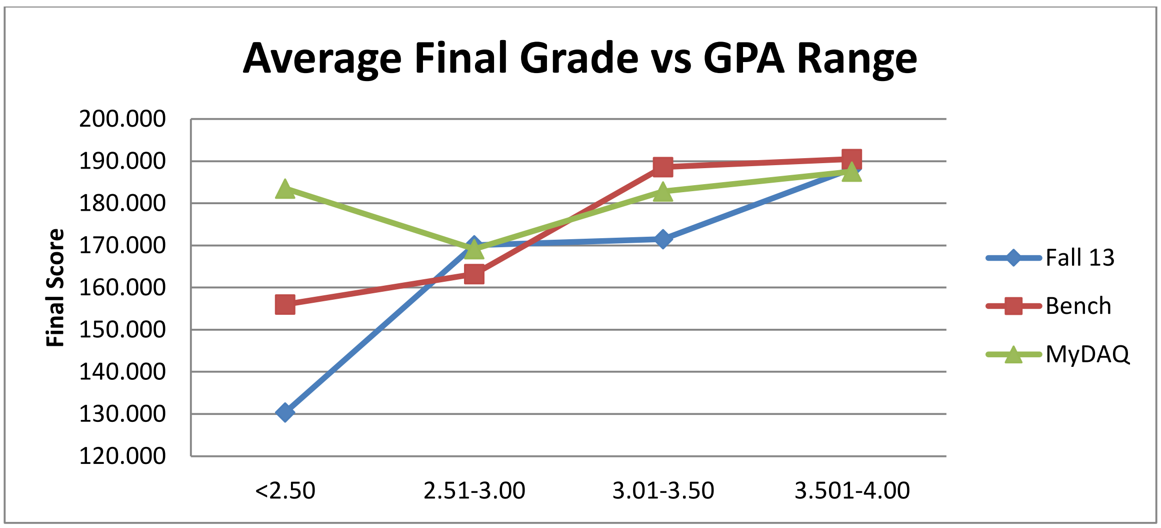


Figure 6.3.2 Average Lab Practicum Final Grade vs GPA Range

For the tables above it should be noted that the sample size for the Bench and MyDAQ cohorts are much smaller than the sample size for the Fall 13 cohort. However, with large sample sizes of the bench and myDAQ cohorts, the same results would likely be found. The only change would be lowering the errors associated with standard deviation.

We can also use descriptive statistics to study our outcome measures in more depth. The change in test score can be used as a proxy for the result of the pre-test and post-test. We would expect this to be a normal distribution. Figure 6.3.3 below shows a histogram of the change in test score values.

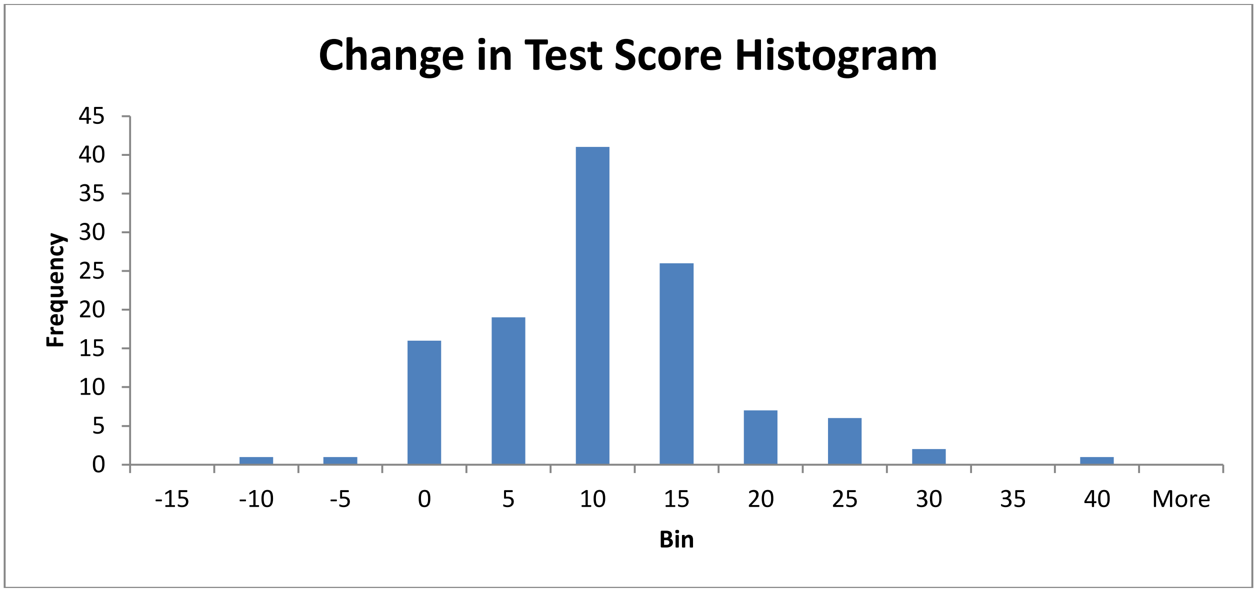


Figure 6.3.3 Change in Test Score Histogram

The histogram in Figure 6.3.3 shows what at first glance appears to be a rather normal distribution. We can see what appears to be an outliers and a tail to the right side. This tail does not mean that the distribution is skewed. Skewedness can be evaluated using the adjusted Fisher-Pearson standardized moment coefficient. The values are adjusted for sample size and will give information about direction of skewedness and comparability to the normal distribution (Doane and Seward, 2011). The adjusted Fisher-Pearson standardized moment coefficient for the data is 0.6465. This indicates the data is skewed and is skewed to the right.

The pre-test and post-test scores showed fairly large standard deviations. These scores were converted to z-scores. A z-score is a method of normalization which accounts for standard deviation and results in the data having a mean equal to zero and a standard deviation equal to 1. Each items z-score is calculated using:

$$z_i = \frac{(x_i - M)}{\sigma}$$

M is the mean score and σ is the standard deviation. The mean and standard deviation for all students regardless of treatment or control group were used to calculate the z-scores. Based on the z-scores a histogram was made to compare the distribution of scores for students in the control and treatment groups.

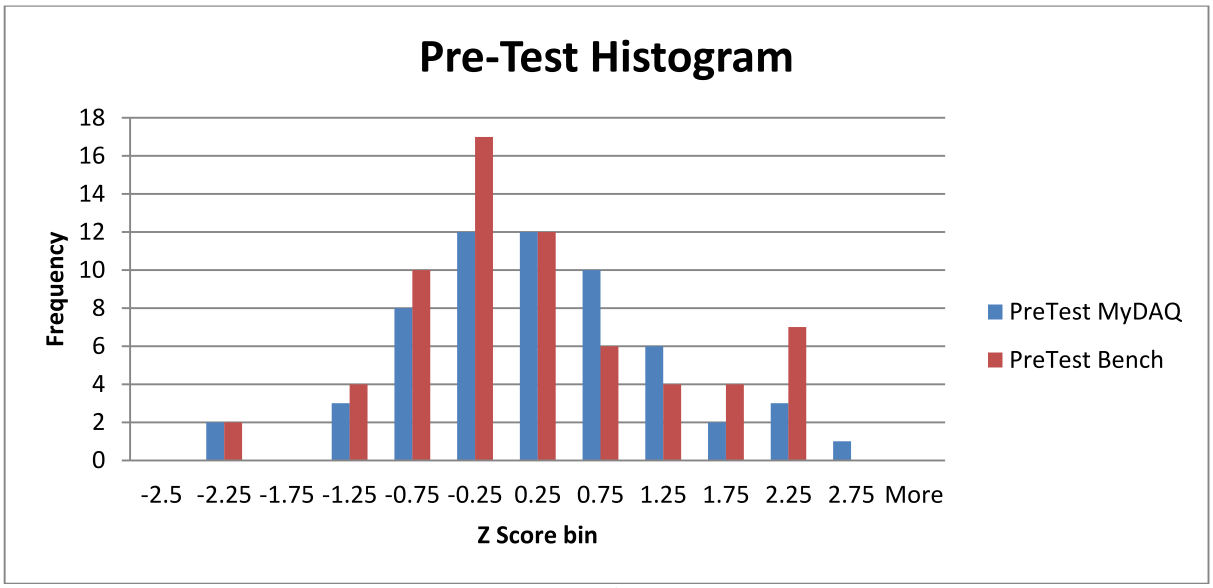


Figure 6.3.4 Histogram of Pre-Test Scores

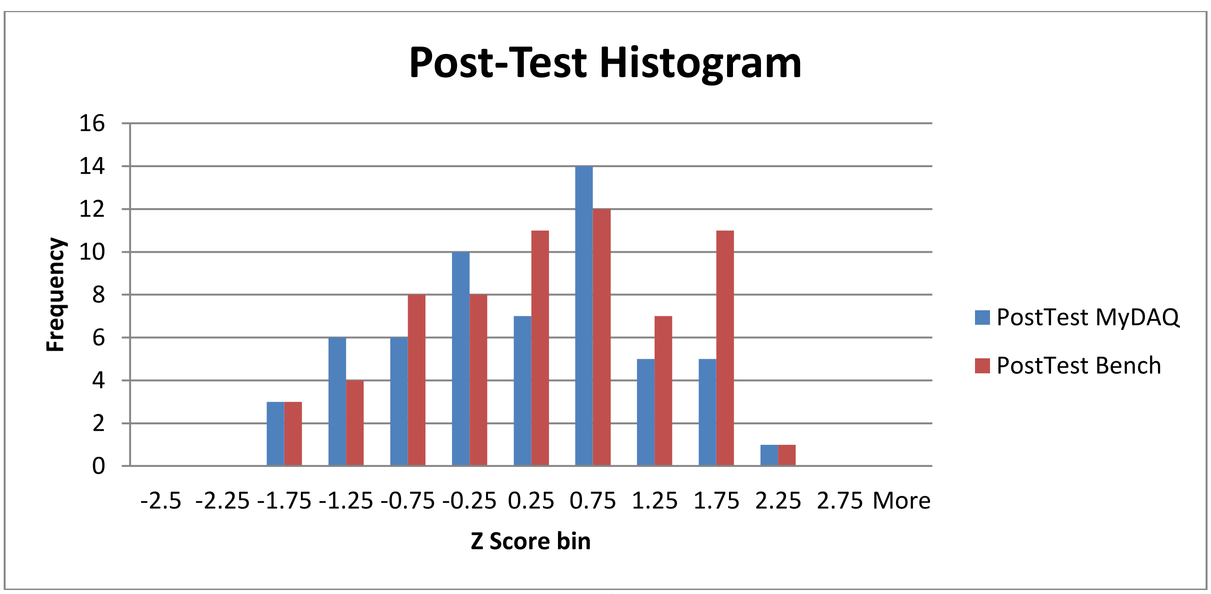


Figure 6.3.5 Histogram of Post-Test Scores

In Figure 6.3.4 and Figure 6.3.5 we see that the distribution of scores is similar for the control group and the treatment group. The total numbers would be different as the population sizes were different, n=59 for treatment group and n=66 for control group. If we look at the z-score for the change in test score from pre-test to post-test we again see the distribution pattern is roughly equal for the two groups.

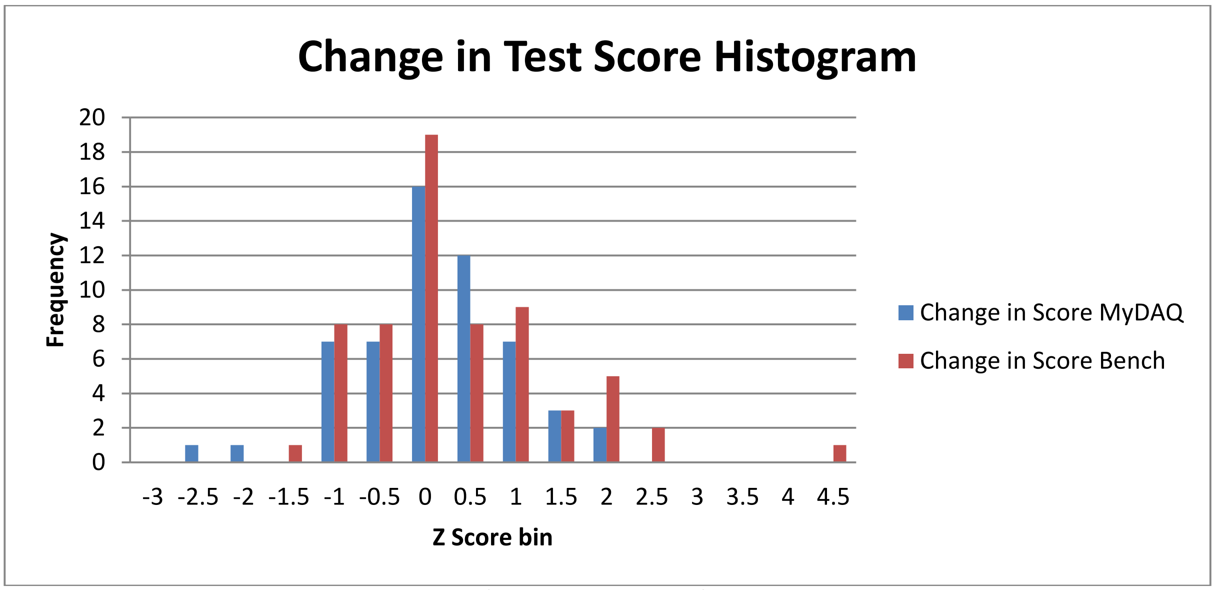


Figure 6.3.6 Histogram for Change in Test score from Pre to Post-test

Figure 6.3.6 above shows the histogram for the change in test score from pre-test to post-test. Again the distribution pattern between the two groups is relatively the same. We do see a few outliers in the histogram which we did not see in the previous ones.

Looking at the z-score we can also find something else of interest. If a t-test assuming equal variance between the pre-test score and the post-test score is conducted we find the following result:

t-Test: Assuming Equal Variances Pre-test and Post-test Score		
	Pre	*Post*
Mean	-0.00264	0.017844
Variance	1.023667	0.994473
Observations	120	120
Pooled Variance	1.00907	
Hypothesized Mean Difference	0	
df	238	
t Stat	-0.15797	
P(T<=t) one-tail	0.437308	
t Critical one-tail	1.651281	
P(T<=t) two-tail	0.874617	
t Critical two-tail	1.969981	

Table 6.3.6 t-Test Between Pre-test and Post-test Scores

Table 6.3.6 above shows the results of the t-test. If we look at the p-values we see that they are large. Meaning there is no statistical significance between pre-test and post-test score. From previous analysis we know they are linked but this result shows us that a low pre-test score does not mean a low post-test score. Rather it shows the post-score was limited by pre-test score

6.4 Use of the myDAQ in the Control Group

Anecdotally during data collection it was mentioned by several students in the control group that they had exposure to the myDAQ through friends and classmates in the treatment group. As students from both groups would be in the same lecture courses, it was reasonable to assume that control group students knew fellow students from the treatment group. This was an unexpected development. A survey was devised to measure the exposure of students in the control group to the myDAQ. The survey gauged student interaction with the myDAQ to having seen someone use it for a demonstration to having used it themselves to collect data. Following each question there was a response line for how often the activity had occurred. The survey was distributed to all of the control group lab sections, but only Section Three returned the surveys completed. The demographics for Section Three compared to all students in the control group are shown below in Table 6.4.1

	Demographics of Control and Section Three						
	GPA			Major			
	Mean	Median	Stdev	EE/EP	ME/MAT	CEG/CS	Other
Bench	3.049	3.061	0.615	25.8%	63.6%	9.1%	3.0%
Section 3	3.150	3.360	0.624	41.2%	41.2%	17.6%	0.0%

Table 6.4.1 Demographics of Control and Section Three

There were 17 students in Section Three and 66 total students in the control group. We can see that students in Section Three had a slightly higher Mean GPA and a Median GPA about a third of a letter grade higher. Also, there were fewer Mechanical Engineering and Materials Science students by percentage than in the entire sample. Likewise there were more Electrical Engineering and Engineering Physics students, and more Computer Engineering and Computer Science students.

The following four questions were asked on the survey relating to exposure to the myDAQ:

1. I had a friend show me stuff on a myDAQ to explain things. How often? (like once, twice, or almost every week)
2. I used a friend's myDAQ to check/redo my data. How often? (like once, twice, or almost every week)
3. I used a friend's myDAQ to just play around with the lab stuff. How often? (like once, twice, or almost every week)
4. I wrote my lab report using data I obtained using a myDAQ rather than the data I collected in the lab. How often? (like once, twice, or almost every week)

Survey answers where the student marked they had the experience but left the frequency blank were counted as a 1 time event. Three students, 17.65%, responded affirmatively to question one. Only one student responded affirmatively to questions two, three, and four. It was the same student answering positively to those questions. This student also answered to question one. The student who answered positively to all four questions was an Electrical Engineering major. The other two students answering in the affirmative to question one were Mechanical Engineering majors. If we extrapolate and assume response rates are about the same across the entire control group, we could expect about 5% of students had done some of the lab activities on a myDAQ even in the control group. About 17% of students had seen someone use the myDAQ to demonstrate some principle of basic analog circuits.

Exposure to the myDAQ even among the control group may be partly responsible for the overall increase in scores from the Fall Semester cohort. However, much more follow up would be needed before any definitive conclusion could be drawn. The data from an entire cohort would need to be collected. Additionally, student attitudes toward the myDAQ would need to be considered. Previous studies (Chsetnutt and Baker 2011, Chun and McCann 2011) have investigated this. However, these studies were conducted at large universities with moderately selective engineering admission requirements. Wright State University has less selective admission policy for engineering students. The prior studies are almost exclusively focused on new first time freshmen student populations. Many of the students in EE 2010L are in their second or third year of an engineering curriculum. Similar outcomes of attitudinal surveys would be expected among Wright State University students, but the demographic differences are enough to make such an investigation of interest. Did students in the control group use the myDAQ because they preferred it or simply because it was the only access they had to lab equipment? This is an important question for consideration. The survey did serve the purpose of answering the question of whether or not control group students were being exposed to the myDAQ.

6.5 Student Response to the myDAQ

Student response to the myDAQ was mostly favorable. Weekly surveys asked students to write one positive aspect of the week's lab activity and one negative aspect of the week's lab activity. The myDAQ was often not mentioned directly. Instead aspects of the myDAQ were mentioned. Students frequently mentioned that they liked the freedom of doing the lab when and where they choose to. Most of the negative responses were related to lab activity directions that students felt were unclear. Other aspects students viewed negatively were related to components. Students mentioned they had difficulty discerning between the different capacitors. In the first few weeks students mentioned getting acclimated to the myDAQ and resolving hardware/software issues as a negative. Once these issues were resolved students tended to have a favorable view of the myDAQ. One particular response came during Week 8 when AC signals, tools, and equipment were being introduced for the first time in the lab. It perhaps best represents students' responses to the myDAQ. Under the question about positive aspects one student wrote, "The myDAQ allows you to experiment with the equipment more". The same student under the question about negative aspects wrote, “myDAQ were a little difficult to get used to (sic)”.

6.6 Discussion and Further Study

Just as was found with the MANOVA and MANCOVA analyses, the only factor which affects student outcomes in all areas was GPA. This suggests the treatment made no difference. The sample size studied in Spring Semester was quite small. As the two groups, the treatment (n=56) and control groups (n=66) in the spring is quite small, there is rather large standard deviation values. Comparisons between larger groups would allow for more impactful comparisons.

Another result that was found was that both control and treatment groups in Spring Semester outperformed the students in the Fall Semester. The lab activities, lab practicum midterm, and final were the same for both semesters. However, in Spring Semester all students performed the lab practica on equipment that they did not regularly use. In the Fall Semester, students performed the lab practica on equipment they used every week for the lab activities. In this case it would be logical to suspect the Fall Semester students would fare better having spent more time on the equipment. By using the same equipment every week the students may have overestimated their lab skills. Assuming they knew how to use the equipment simply because they used it every week, may have caused them to under prepare for the lab practica. Anecdotally it seemed in the Spring Semester students were requesting help and additional lab time to study for the lab practica. During this study time students were asking more questions about how the lab equipment functioned rather than just how to use it to get the answer they needed.

A formal measure of students' opinions of their abilities in the future could confirm or disprove the previous assumption. However, any future study would need to be primarily focused upon creating a larger data sample.

7 Discussion and Moving Forward in EE 2010L Circuit Analysis Lab

7.1 Discussion

During the Spring Semester of 2013 EE 2010L students were divided into two test groups. The control group performed the weekly lab activities on a traditional bench lab set up. The treatment groups were exposed to a different pedagogical method which used myDAQs to allow the students to do the labs at home on their own time. Both groups took a lab practicum midterm and a lab practicum final on bench equipment they had not worked on previously. Both groups were administered the Electric Circuits Concepts Evaluation (ECCE) as a pre-test on the first day of lab and as a post-test at the end of the term. The students in the treatment sections were also provided with open lab times throughout the week where they could consult with the Teaching Assistants if they had questions, concerns, or problems using the myDAQ. Each week in the lab meeting students in the treatment group section were selected at random to present and demonstrate how they accomplished part of the weekly lab activity. Treatment group students also completed a weekly survey about their experience with the myDAQ that week and provided how long they spent collecting data. The control group signed out of lab each week in order to measure how long they had spent in the lab collecting data. Both groups performed the same weekly lab activities using the same circuit components.

A quasi experimental design was used. It is not possible to assign students to courses at complete random, so the courses were scheduled to maximize the randomness of student registration. Lab sections for the semester were scheduled in pairs. One control group lab was scheduled at the same time as one test group lab. During the registration process students did not know if they were signing up for a control group or a treatment group. These paired lab times produced as random an assignment of students to labs as possible. It was important to establish as random a registration of students as possible so that the control group and treatment groups would have similar demographics and fair and equal comparisons could be made.

Students entering EE 2010L have a wide variety of backgrounds and range of previous exposure to the ideas of analog circuits. As such, it is a difficult task to develop labs that are challenging for the most experienced student but not to challenging for the students with the least prior exposure. Consequently there is a wide variety of time students spend collecting data. We see that in a traditional lab there are students spending nearly the entire lab period collecting data when most of their peers are done in half the time. As a result, the student time collecting data was of interest. The treatment group reported spending longer on the labs than the control group students did. There are several possible explanations for this. First students using the myDAQ in the treatment group worked individually. Each student had their own myDAQ. The control group students who did the bench labs worked in partners. This collaboration may speed up the process. However, collaboration limits student access to the equipment. It is possible for a weaker student to partner with a very strong student and complete the lab activity without fully understanding what has happened or why they received the results that they did. The individual nature of data collection prevents students from simply becoming a scribe in the lab. A second possible explanation is that in using the myDAQ students did not feel the pressure to finish in a given amount of time. Traditional lab sections have a set end time. When a student uses a myDAQ they may be able to start and stop without fear of running out of time and not having enough data to write a lab report. With the time constraint removed students can move at slower pace more appropriate to their level of understanding without the competition of trying to finish when everyone else finishes.

A third, and hoped for occurrence, was that students struggled more with the myDAQ than in a bench lab. Without the immediate feedback and correction from a TA the student may struggle. Struggling is not necessarily a bad thing. The students knew there was a designated time and place to go and get help. If they are at a complete loss for how to proceed they can put the equipment away, go get help, and return to the problem later. While struggling, students are gaining valuable analytical and trouble shooting skills. Trouble shooting a circuit is an important skill to develop and is also one of the hardest skills to teach. While students are struggling they may also begin to develop their own experiments. It is difficult for a student to damage a myDAQ to the point where it will not function. Thus, these student initiated investigations are occurring in a relatively safe environment. A traditional lab setting does not foster such individual exploration. Standard lab equipment is not as robust. Students often feel like they are doing something wrong if they try out new things with a Teaching Assistant watching. The treatment appears to be a practical method for expanding lab time for everyone without overburdening the weaker students. Students can move at a pace that is appropriate to their level of understanding. This is an improvement over the traditional lab.

In examining this study it is important to evaluate student learning. Prior to this study, the student success rate in EE 2010L, based on student final grades, had not been as high as hoped. The new pedagogical method of the inverted lab time and frequented demonstration by students was created to try and change this.   Student learning outcomes were measured in several ways. The first was the lab practicum midterm exam. The same exam was given to students in the Fall Semester. Students in the Fall Semester used the regular lab equipment for the exam while students in the Spring Semester used equipment they had not seen before. The second measure was the lab practicum final. Similar to the midterm, the same exam was administered in Fall Semester using familiar equipment and in Spring Semester it was given using equipment the students were unfamiliar with. One of the most important outcomes from any lab is the portability of the students' skills. That is to say, how easy is it for a student who has learned on one piece of equipment to adapt and use equipment that is similar but not exactly the same? An oscilloscope is an oscilloscope. A student should be able to use one regardless of whether it is manufactured by Hewlett Packard or Agilent Technologies. The scores on the practica were truer measure of how well students learned to perform the lab task and use the basic lab equipment rather than just how well they knew how to use one particular set.

The final measurement of student learning was the pre-test and post-test scores. The pre-test and post-test measured the students' theoretical knowledge. The pre-test and post-test scores will be heavily influenced by students' prior knowledge in the area. To account for this Hake's gain was used for the MANOVA and MANCOVA analyses. The ECCE exam has 45 multiple choice questions, with four of these questions requiring a short written explanation. Student scores were recorded out of 49 points. The highest score achieved on the pre-test was a 36. All students had ample room for improvement from pre-test to post-test. However, students who performed well initially had less room, hence the use of Hake's Gain. All items on the ECCE exam were used for analysis. All the questions could be mapped to course learning objectives. Given this fact, it was deemed appropriate to include the students' total score.

Initially there were several factors identified which would likely impact student success, lab type (treatment or control group), student major, GPA, lecture section, and Teaching Assistant. It was quickly identified that a student's major would have a significant impact upon which lecture section a student enrolled in and lecture section was dropped from consideration. A MANOVA analysis was carried out. The only factor identified as being statistically significant was GPA. This is the result we would expect even if there had been no treatment. Students with higher GPAs tend to perform better on measures of learning outcome. The MANOVA was followed up with a MANCOVA and post hoc testing. All of which showed the same response that only GPA had an impact on students learning. The type of lab students were in did not make a difference. It did not matter which TA a student had or what their major was. It was only the GPA that has a statistically significant impact on the measured outcome.

The stated hypothesis was: Students using the myDAQ will perform better at measuring current, voltage, and resistance in basic analog circuits containing resistors, capacitors, and inductors with both DC and AC sources. These students will also have a better understanding of the current and voltage relationship for resistors in series and resistors in parallel. The results disprove the initial hypothesis. However, they show something important for the learning outcomes. The new pedagogical method did not have a negative impact upon student learning. It did no harm. It increased the amount of time students spent collecting data and working on actual lab exercises. Overall, the study could be considered a success. It showed student learning outcomes were not dependent upon TA, the lab equipment used, or instructional style. The new instructional method, which produces equal results, has several benefits over the traditional method. First, it allows each student access to an individual set of equipment. This cuts down on a student's ability to "hide" in lab. A weaker student can no longer simply partner up with a stronger student and just record data. Secondly, the students are spending more total time on the labs. This time spent collecting data can be allocated how the student wants. If a student wants to do the whole lab at once they can. If they want to do part now and part later, they can. It makes the lab experience more amenable to each individual students pace and preferred time management style. Additionally, there is the cost benefit. The myDAQ and protoboard used cost $250. A typical bench lab set up can run nearly $10,000. Since the equipment is so expensive, most universities can only buy a finite amount and then cannot allow students unlimited access. Perhaps, most importantly is what the different method means for the future of EE 2010L. All of the above mentioned benefits together will allow a shift in how the course is taught. This pedagogical method will allow the lab to be more project oriented and less based on lab activities with a predetermined outcome.

7.2 Moving Forward in EE 2010L

As an introductory lab EE 2010L, and its predecessor EE 302, has been based on a series of lab activities where the outcome can be easily predicted and is readily known based on analytical methods. Most engineers in the field do not spend their time working on physical solutions to problems which can be calculated analytically. Introductory labs face a unique challenge. They must instill in students a sound fundamental education in the theories of material. Yet, they most also begin to challenge students to perform the everyday work of an engineer. Engineers need to be able to apply the fundamentals and create a solution (Sheppard & Jennison, 1997). This is the design phase of engineering. An introductory course needs to introduce students to this concept. It should encourage students to begin to think about how to create a solution to an open-ended problem and how to realize the first attempt will not always produce the solution. Instead, the solution evolves from redesigning an initial design and refining elements in it. Also, there is no one "right" answer to most engineering design problems.

This can be accomplished through introducing Problem Based Learning, PBL, into the course. PBL also meets several criteria which are stressed by ABET, such as teamwork and lifelong learning. Simply described, students are provided with a problem with many correct answers and must work collaboratively to reach a solution. Students are responsible for indentifying what they need to learn to solve the problem (Hmelo-Silver, 2004). This is already done as part of the curriculum at Wright State. As part of

ABET accreditation, every engineering discipline at Wright State University has a senior design course that is a large scale PBL course.

Using the new pedagogical method of the myDAQ and classroom presentations, PBL can be added into the EE 2010L curriculum. As the fundamentals are important and student backgrounds vary widely, the course would not be entirely based on PBL. Instead it would consist of a hybrid. The course could contain some closed in lab activities to teach basic lab skills, mixed in with some open-ended group projects. The results of this study show the myDAQ is just as effective as a traditional lab course. This can be used to improve the curriculum. It can also be the basis for further study. Outlined below is a sample time line of events and opportunities for improving the EE 2010L curriculum.

- Spring Semester 2015 & Summer Semester 2015 - All lab sections use the myDAQ enabled alternative pedagogical method. Students become responsible for the purchase of their own myDAQ and protoboard. Students will take the same lab practicum final and midterm as was administered in Fall 13 and Spring 14. At the same time new projects are designed and tested for future use in the course.
- Fall 2015 - A new curriculum for EE 2010L will make its debuts. Students will perform two weeks of fixed lab experiments to gain familiarity with the basics of DC analog circuit equipment. Next, students will spend 5 weeks working collaboratively on a project. Students will then have another week of fixed lab activities to learn the basics of AC equipment. Students can then spend the remainder of the term working on another collaborative project using AC circuits.

Students will again take the same lab practicum midterm and final. They will also have to present their projects to the class.

The proposed fixed lab activities in Fall 15 will be much longer and more in depth than any single week's lab activity that is currently used. In essence it will consist of several of the current lab activities combined into one big lab. Using an inverted lab will mean the size of the closed-ended labs can grow in size and are not constrained to fitting into a 150 minutes once a week. To make sure students are progressing in their projects they will still need to come to lab every week to report on and demonstrate their progress. The lab practica will serve as a measuring stick so that comparison can be made across semesters. It can also serve as a nice barometer for finding the right balance of fixed labs and open-ended projects.

This will be a difficult process. There are many parts which remain to be done. The new fixed lab activities need to be created. The concepts for projects need to be created and refined. Enough projects will need to be created so that the same projects do not repeat every term. The most important piece is TA training. The lab course is nothing without an effective TA. The TAs will need to be trained on how to use the myDAQ. What are its limitations and strengths? They will also need to be trained on PBL. If the TAs do not understand PBL and do not buy into it, you will likely end up with a class full of projects that look very similar. Also important, and perhaps the most difficult of all, is to change how EE 2010L is staffed and viewed. Introductory courses provide an opportunity to spark students' imaginations and hook them on the topic. Introductory courses can be seen by faculty and TAs as boring and simplistic. As this is the first exposure for students to the topics, they often require more preoperational work and more of a desire to be there by the instructor.

Quality labs require an investment of time, money, and effort. Hopefully the results of this study will show that EE 2010L Circuit Analysis Lab does not need to be a series of closed-ended traditional lab activities. The hope is it will spur the development and further study of turning the course into a more open-ended course.

Appendix A Spring 14 Semester Data

EE2010L Spring 14 Students Data											
ID	**Major**	**GPA**	**Lecture**	**Lab**	**Lab Type**	**TA**	**Midterm**	**Final**	**Pre-Test**	**Post-Test**	**Gain**
S140003	Mech Engineering	4.000	1	3	Bench	Alpha	100	200	24	40	0.640
S140004	Computer Engineering	3.070	1	1	Bench	Echo	100	195	10	25	0.385
S140006	Mathematics	4.000	1	4	MyDAQ	Bravo	100	200	22	34	0.444
S140009	Computer Engineering	3.984	1	8	MyDAQ	Alpha	100	175	28	38	0.476
S140010	Computer Engineering	3.622	1	7	Bench	Bravo	80	190	33	40	0.438
S140012	Mech Engineering	2.312	1	6	Bench	Foxtrot	76	180	15	23	0.235
S140014	Electrical Engineer	2.702	1	7	Bench	Bravo	100	150	12	31	0.514
S140015	Computer Engineering	2.834	1	4	MyDAQ	Bravo	100	200	22	37	0.556
S140017	Mech Engineering	2.113	1	3	Bench	Alpha	80	145	17	28	0.344
S140019	Mech Engineering	3.504	1	7	Bench	Bravo	100	170	26	30	0.174
S140020	Computer Engineering	2.127	1	5	Bench	Delta	100	135	20	19	-0.034
S140022	Mech Engineering	3.280	1	4	MyDAQ	Bravo	100	200	18	32	0.452
S140023	Mech Engineering	2.805	1	8	MyDAQ	Alpha	60	30	12	14	0.054
S140027	Mech Engineering	2.788	1	4	MyDAQ	Bravo	78	180	20	25	0.172
S140029	Mech Engineering	3.883	1	5	Bench	Delta	95	175	30	30	0.000
S140033	Mech Engineering	2.248	1	1	Bench	Echo	80	195	11	24	0.342
S140036	Mech Engineering	3.375	1	1	Bench	Echo	100	200	14	21	0.200
S140039	Mech Engineering	2.741	1	1	Bench	Echo	100	200	18	26	0.258
S140040	Mech Engineering	2.758	1	8	MyDAQ	Alpha	100	175	20	28	0.276
S140043	Mech Engineering	3.671	1	5	Bench	Delta	100	200	31	37	0.333
S140052	Mech	3.767	1	5	Bench	Delta	100	190	29	34	0.250

	Engineering										
S140053	Mech Engineering	3.868	1	5	Bench	Delta	100	200	23	38	0.577
S140056	Mech Engineering	3.473	1	4	MyDAQ	Bravo	100	200	32	39	0.412
S140060	Mech Engineering	3.937	1	8	MyDAQ	Alpha	100	200	27	37	0.455
S140063	Mech Engineering	2.687	1	6	MyDAQ	Foxtrot	100	200	13	21	0.222
S140066	Mech Engineering	3.550	1	2	MyDAQ	Alpha	100	195	22	28	0.222
S140070	Mech Engineering	3.824	1	4	MyDAQ	Bravo	100	200	11	33	0.579
S140073	Mech Engineering	3.850	1	5	Bench	Delta	100	200	33	37	0.250
S140075	Computer Engineering	2.243	1	4	MyDAQ	Bravo	100	190	18	24	0.194
S140083	Electrical Engineer	2.833	1	4	MyDAQ	Bravo	60	100	14	20	0.171
S140092	Electrical Engineer	3.300	1	4	MyDAQ	Bravo	100	195	28	28	0.000
S140097	Mech Engineering	3.433	1	3	Bench	Alpha	100	200	16	30	0.424
S140099	Electrical Engineer	2.103	1	2	MyDAQ	Alpha	100	195	13	28	0.417
S140101	Industr + Systems Egr	2.366	1	5	Bench	Delta	93	90	19	25	0.200
S140102	Electrical Engineer	3.806	1	3	Bench	Alpha	100	175	29	37	0.400
S140115	Mech Engineering	2.838	1	3	Bench	Alpha	88	200	11	31	0.526
S140122	Electrical Engineer	4.000	1	7	Bench	Bravo	100	200	30	40	0.526
S140124	Mech Engineering	3.500	1	4	MyDAQ	Bravo	100	175	31	30	-0.056
S140001	Electrical Engineer	2.200	2	8	MyDAQ	Alpha	100	200	9	15	0.150
S140005	Mech Engineering	2.465	2	1	Bench	Echo	66.8	135	8	19	0.268
S140008	Computer Engineering	3.129	2	2	MyDAQ	Alpha	100	170	14	24	0.286
S140011	Electrical Engineer	3.018	2	8	MyDAQ	Alpha	100	155	21	8	-0.464
S140018	Materials Sci + Egr	2.405	2	2	MyDAQ	Alpha	100	175	9	17	0.200
S140021	Computer Engineering	3.358	2	3	Bench	Alpha	100	165	32	41	0.529
S140025	SW Ohio Council for	2.790	2	6	MyDAQ	Foxtrot	100	200	21	29	0.286

	Higher Ed										
S140026	Mech Engineering	3.278	2	2	MyDAQ	Alpha	100	200	17	24	0.219
S140028	Mech Engineering	2.516	2	2	MyDAQ	Alpha	100	200	24	32	0.320
S140031	Mech Engineering	2.655	2	6	MyDAQ	Foxtrot	66	200	11	13	0.053
S140032	Mech Engineering	2.787	2	1	Bench	Echo	100	145	18	26	0.258
S140035	Electrical Engineer	1.875	2	3	Bench	Alpha	100	115	11	26	0.395
S140045	Mech Engineering	3.769	2	8	MyDAQ	Alpha	100	200	25	37	0.500
S140046	Mech Engineering	3.555	2	2	MyDAQ	Alpha	100	190	18	9	-0.290
S140047	Mech Engineering	2.982	2	2	MyDAQ	Alpha	100	200	24	30	0.240
S140048	Electrical Engineer	1.500	2	4	MyDAQ	Bravo	100	170	16	29	0.394
S140049	Mech Engineering	3.625	2	3	Bench	Alpha	100	175	24	31	0.280
S140051	Electrical Engineer	3.931	2	3	Bench	Alpha	100	200	12	38	0.703
S140054	Mech Engineering	3.776	2	2	MyDAQ	Alpha	100	160	33	32	-0.063
S140055	Electrical Engineer	3.121	2	4	MyDAQ	Bravo	20	200	0	13	0.265
S140058	Mech Engineering	2.815	2	3	Bench	Alpha	80	150	9	15	0.150
S140059	Mech Engineering	2.980	2	2	MyDAQ	Alpha	100	195	14	17	0.086
S140062	Electrical Engineer	3.423	2	3	Bench	Alpha	60	190	8	35	0.659
S140064	Mech Engineering	3.437	2	7	Bench	Bravo	100	200	31	32	0.056
S140065	Mech Engineering	3.111	2	8	MyDAQ	Alpha	100	195	7	11	0.095
S140071	Electrical Engineer	4.000	2	4	MyDAQ	Bravo	100	200	24	35	0.440
S140074	Electrical Engineer	4.000	2	6	MyDAQ	Foxtrot	100	190	26	30	0.174
S140076	Electrical Engineer	3.315	2	2	MyDAQ	Alpha	67	200	6	22	0.372
S140077	Computer Engineering	2.984	2	8	MyDAQ	Alpha	80	185	10	22	0.308
S140080	Mech Engineering	2.865	2	5	Bench	Delta	78	140	22	27	0.185
S140081	Mech Engineering	2.714	2	5	Bench	Delta	95	135	12	33	0.568

S140084	Electrical Engineer	3.607	2	3	Bench	Alpha	100	200	13	35	0.611
S140087	Electrical Engineer	2.307	2	8	MyDAQ	Alpha	100	195	14	12	-0.057
S140088	Mech Engineering	2.754	2	5	Bench	Delta	100	160	17	18	0.031
S140090	Electrical Engineer	2.305	2	1	Bench	Echo	100	155	17	17	0.000
S140091	Mech Engineering	2.162	2	1	Bench	Echo	100	135		13	
S140100	Mech Engineering	3.333	2	1	Bench	Echo	100	195	12	26	0.378
S140103	Electrical Engineer	3.052	2	3	Bench	Alpha	94	200	13	11	-0.056
S140108	Electrical Engineer	3.724	2	6	MyDAQ	Foxtrot	100	200	12	23	0.297
S140110	Mech Engineering	3.531	2	1	Bench	Echo	100	200	12	19	0.189
S140111	Materials Sci + Egr	2.894	2	2	MyDAQ	Alpha	93	145		20	
S140113	Electrical Engineer	3.172	2	7	Bench	Bravo	100	200	14	35	0.600
S140114	Electrical Engineer	2.040	2	2	MyDAQ	Alpha	100	170	19	29	0.333
S140118	Mech Engineering	3.041	2	6	MyDAQ	Foxtrot	98	200	12	21	0.243
S140119	Computer Engineering	2.785	2	3	Bench	Alpha	100	180	7	13	0.143
S140120	Computer Engineering	3.714	2	3	Bench	Alpha	100	195	7	29	0.524
S140123	Electrical Engineer	4.000	2	5	Bench	Delta	95	195	15	28	0.382
S140002	Mech Engineering	2.178	3	8	MyDAQ	Alpha	100	195	21	34	0.464
S140007	Computer Engineering	3.923	3	6	MyDAQ	Foxtrot	100	190	11	27	0.421
S140013	Mech Engineering	3.416	3	1	Bench	Echo	100	175	24	25	0.040
S140016	Mech Engineering	3.137	3	4	MyDAQ	Bravo	100	190	16	22	0.182
S140030	Materials Sci + Egr	2.685	3	2	MyDAQ	Alpha	80	180	6	12	0.140
S140034	Mech Engineering	3.650	3	7	Bench	Bravo	94	180	22	33	0.407
S140037	Mech Engineering	3.377	3	7	Bench	Bravo	80	145	15	26	0.324
S140038	Mech Engineering	3.063	3	6	MyDAQ	Foxtrot	100	200	11	24	0.342
S140041	Mech	2.288	3	1	Bench	Echo	40	125	11	9	-0.053

	Engineering										
S140042	Electrical Engineer	2.851	3	4	MyDAQ	Bravo	100	180	16	19	0.091
S140044	Mech Engineering	2.500	3	1	Bench	Echo	82.5	155	9	9	0.000
S140050	Electrical Engineer	1.533	3	7	Bench	Bravo	80	180	0	40	0.816
S140057	Mech Engineering	2.803	3	2	MyDAQ	Alpha	100	180	18	16	-0.065
S140061	Mech Engineering	3.641	3	7	Bench	Bravo	94	190	16	31	0.455
S140067	Mech Engineering	3.411	3	7	Bench	Bravo	100	195	19	33	0.467
S140068	Mech Engineering	2.656	3	7	Bench	Bravo	100	200	13	20	0.194
S140069	Mech Engineering	2.868	3	7	Bench	Bravo	80	195	23	23	0.000
S140072	Electrical Engineer	2.096	3	4	MyDAQ	Bravo	20		16		
S140078	Electrical Engineer	2.268	3	1	Bench	Echo	100	195	13	19	0.167
S140079	Mech Engineering	2.688	3	5	Bench	Delta	100	185	14	20	0.171
S140082	Mech Engineering	2.469	3	6	MyDAQ	Foxtrot	60	150	14	25	0.314
S140085	Electrical Engineer	3.521	3	4	MyDAQ	Bravo	100	200	22	23	0.037
S140086	Electrical Engineer	3.281	3	5	Bench	Delta	85	175	14	23	0.257
S140089	Mech Engineering	2.428	3	1	Bench	Echo	89	200	16	13	-0.091
S140093	Mech Engineering	2.653	3	7	Bench	Bravo	100	160	10	20	0.256
S140094	Electrical Engineer	3.754	3	2	MyDAQ	Alpha	80	125	16	32	0.485
S140095	Mech Engineering	2.875	3	1	Bench	Echo	60	200	12	10	-0.054
S140096	Electrical Engineer	3.448	3	4	MyDAQ	Bravo	100	145	13	23	0.278
S140098	Electrical Engineer	2.586	3	8	MyDAQ	Alpha	100	125	10	8	-0.051
S140104	Mech Engineering	2.375	3	7	Bench	Bravo	60	155	19	27	0.267
S140105	Electrical Engineer	2.214	3	3	Bench	Alpha	100	200	33	37	0.250
S140106	Electrical Engineer	3.578	3	8	MyDAQ	Alpha	100	175	36	41	0.385
S140107	Mech Engineering	2.307	3	6	MyDAQ	Foxtrot	66.6	195	19	18	-0.033

S140109	Electrical Engineer	3.903	3	8	MyDAQ	Alpha	100	200	12	34	0.595
S140112	Mech Engineering	3.360	3	3	Bench	Alpha	94	200	10	16	0.154
S140116	Electrical Engineer	3.535	3	3	Bench	Alpha	80	175	11	29	0.474
S140117	Mech Engineering	2.875	3	1	Bench	Echo	100	190	20	23	0.103
S140121	Mech Engineering	2.296	3	2	MyDAQ	Alpha	97		20		
S140125	Electrical Engineer	3.666	3	5	Bench	Delta	90	200	34	37	0.200
S140024	Mech Engineering	2.662	NA	7	Bench	Bravo	100	30	19		-0.633

Appendix B Fall 13 Semester Data

EE2010L Fall 13 Students Data						
ID	**Major**	**GPA**	**Lecture**	**Lab**	**Midterm**	**Final**
F13015	Electrical Engineer	2.785	1	1	100	190
F13080	Mech Engineering	3.293	1	1	100	150
F13098	Electrical Engineer	2.354	1	1	28	140
F13119	Computer Engineering	2.121	1	1	24	139
F13122	Computer Engineering	2.366	1	1	22	65
F13126	Electrical Engineer	0.000	1	1	82	0
F13014	Mech Engineering	3.070	2	1	64	185
F13025	Computer Engineering	3.699	2	1	90	150
F13043	Computer Engineering	2.901	2	1	94	185
F13076	Mech Engineering	1.884	2	1	58	165
F13082	Mech Engineering	2.487	2	1	64	170
F13093	Mech Engineering	2.166	2	1	26	190
F13094	Electrical Engineer	3.214	2	1	82	179
F13005	Electrical Engineer	3.562	3	1	100	190
F13010	Computer Engineering	3.071	3	1	100	175
F13071	Electrical Engineer	3.584	3	1	88	180
F13110	Electrical Engineer	2.190	3	1	88	195
F13004	Electrical Engineer	2.714	1	2	82	200
F13007	Mech Engineering	3.318	1	2	82	200
F13028	Mech Engineering	3.505	1	2	100	200
F13030	Mech Engineering	2.065	1	2	100	195
F13033	Electrical Engineer	2.187	1	2	64	165
F13035	Mech Engineering	1.968	1	2	82	145
F13042	Mech Engineering	2.795	1	2	74	172
F13053	Computer Engineering	2.225	1	2	82	195
F13067	Mech Engineering	3.217	1	2	100	195
F13083	Electrical Engineer	2.786	1	2	100	175
F13096	Electrical Engineer	1.869	1	2	82	150
F13097	Electrical Engineer	2.301	1	2	46	135
F13099	Electrical Engineer	1.994	1	2	52	100
F13060	Mech Engineering	2.655	2	2	18	30
F13095	Mech Engineering	2.767	2	2	100	155
F13012	Mech Engineering	2.034	1	3	82	155
F13013	Mech Engineering	3.464	1	3	78	145
F13027	Mech Engineering	2.980	1	3	64	190

F13040	Mech Engineering	1.550	1	3	100	0
F13075	Mech Engineering	2.701	1	3	64	175
F13116	Mech Engineering	2.152	1	3	82	0
F13024	Mech Engineering	3.099	2	3	100	200
F13031	Computer Engineering	2.788	2	3	82	155
F13041	Computer Engineering	3.196	2	3	84	140
F13044	Mech Engineering	2.988	2	3	100	195
F13047	Mech Engineering	2.836	2	3	94	200
F13055	Mech Engineering	3.471	2	3	100	180
F13056	Mech Engineering	2.803	2	3	54	175
F13057	Mech Engineering	3.302	2	3	100	200
F13079	Mech Engineering	2.647	2	3	82	190
F13104	Mech Engineering	2.425	2	3	72	130
F13106	Electrical Engineer	3.481	2	3	90	195
F13115	Mech Engineering	3.500	2	3	82	175
F13118	Electrical Engineer	1.800	2	3	0	0
F13100	Electrical Engineer	2.440	3	3	100	190
F13125	Electrical Engineer	3.473	3	3	100	200
F13018	Mech Engineering	2.172	1	4	100	195
F13021	Mech Engineering	2.624	1	4	76	200
F13036	Electrical Engineer	2.809	1	4	100	180
F13050	Mech Engineering	3.415	1	4	94	190
F13069	Electrical Engineer	2.789	1	4	54	105
F13113	Mech Engineering	3.785	1	4	100	200
F13120	Electrical Engineer	3.000	1	4	76	200
F13016	Mech Engineering	2.854	2	4	82	195
F13029	Mech Engineering	2.678	2	4	100	130
F13038	Industr + Systems Egr	2.420	2	4	24	180
F13046	Electrical Engineer	3.381	2	4	100	190
F13052	Electrical Engineer	2.529	2	4	78	100
F13054	Computer Engineering	3.389	2	4	82	200
F13058	Mech Engineering	2.600	2	4	64	155
F13070	Electrical Engineer	3.634	2	4	94	185
F13078	Electrical Engineer	2.425	2	4	90	190
F13081	Mech Engineering	2.686	2	4	48	90
F13087	Electrical Engineer	3.285	2	4	82	165
F13089	Electrical Engineer	2.037	2	4	54	120
F13017	Mech Engineering	2.437	1	5	100	170
F13062	Mech Engineering	3.037	1	5	100	145
F13066	Mech Engineering	2.820	1	5	70	195
F13074	Electrical Engineer	3.121	1	5	6	0

F13090	Mech Engineering	2.982	1	5	94	190
F13103	Electrical Engineer	2.364	1	5	94	195
F13037	Mech Engineering	3.167	2	5	100	190
F13073	Biomedical Engineering	3.714	2	5	100	185
F13092	Mech Engineering	2.459	2	5	88	175
F13114	Mech Engineering	3.911	2	5	100	200
F13003	Mech Engineering	3.142	3	5	94	170
F13061	Mech Engineering	2.753	3	5	100	160
F13002	Engineering Physics	2.794	1	6	100	165
F13026	Integrated Science - BS	2.736	1	6	82	200
F13032	Mech Engineering	2.880	1	6	52	175
F13048	Business - Intent	2.066	1	6	90	53
F13077	Electrical Engineer	2.208	1	6	36	0
F13084	Electrical Engineer	4.000	1	6	100	200
F13101	Mech Engineering	2.333	1	6	58	100
F13112	Computer Engineering	2.469	1	6	100	200
F13022	Computer Engineering	2.973	2	6	94	185
F13023	Mech Engineering	3.777	2	6	100	200
F13045	Mech Engineering	1.957	2	6	94	140
F13072	Electrical Engineer	2.666	2	6	64	140
F13088	Mech Engineering	2.709	2	6	100	170
F13059	Electrical Engineer	2.854	3	6	100	190
F13008	Computer Engineering	2.388	1	7	52	185
F13108	Electrical Engineer	2.000	1	7	0	0
F13051	Computer Engineering	4.000	2	7	76	190
F13006	Computer Engineering	2.966	3	7	90	190
F13020	Electrical Engineer	2.173	3	7	76	195
F13063	Mech Engineering	2.673	3	7	46	150
F13065	Biomedical Engineering	3.176	3	7	84	165
F13102	Mech Engineering	4.000	3	7	82	195
F13105	Mech Engineering	3.053	3	7	78	165
F13049	Mech Engineering	2.307	1	8	0	120
F13064	Mech Engineering	2.819	1	8	82	200
F13109	Mech Engineering	3.620	1	8	78	160
F13111	Mech Engineering	3.131	1	8	100	175
F13107	Mech Engineering	2.438	2	8	0	0
F13123	Materials Sci + Egr	4.000	2	8	70	200
F13001	Electrical Engineer	2.727	3	8	40	200
F13009	Electrical Engineer	2.366	3	8	100	190
F13011	Mech Engineering	1.739	3	8	100	195
F13019	Electrical Engineer	2.192	3	8	88	195

F13034	Mech Engineering	2.483	3	8	72	185
F13039	Mech Engineering	3.000	3	8	90	185
F13068	Mech Engineering	2.706	3	8	66	170
F13085	Computer Engineering	2.696	3	8	90	195
F13086	Mech Engineering	2.171	3	8	54	135
F13091	Electrical Engineer	1.747	3	8	10	0
F13117	Mech Engineering	1.857	3	8	12	115
F13121	Electrical Engineer	2.350	3	8	28	140
F13124	Mech Engineering	3.071	3	8	90	185

Appendix C Midterm Lab Practicum

Name: ____________________ Lab TA Name: ___________________
Lab section number: _________________ Date:___________________

You will have 45 minutes maximum to complete the quiz. You are to work on it individually and will receive no help from the TA. If you are talking to other students the TA will take your Quiz and you will receive a zero on the lab. If anything catches fire or begins to smoke the TA will take your quiz and you will receive a zero.

1.) You have 3 different colored resistors. You will build two circuits
2.) To find the resistance of each resistor. Write in the colors on the tables below

Resistor Color	Resistance

3.) Use the breadboard to build a circuit consisting of the three resistors in series. Measure the values asked for in the table below. Connect the circuit to the power supply set to 2 V

Resistor Color	Voltage	Current

4.) Use the breadboard to build a circuit consisting of the three resistors in parallel. Measure the values asked for in the table below. Connect the circuit to the power supply set to 2 V

Resistor Color	Voltage	Current

5.) Disassemble your circuit and turn this sheet in to the TA

Appendix D Final Lab Practicum

EE 2010L Lab Final

Name: ____

Directions: You have 1 hour to complete the lab final. In front of you is a breadboard with two set ups. The first is just resistor network the second is a resistor and capacitor network. Your Lab Instructor will answer NO questions you are to know all the material covered in the exam. You are not to talk to anyone. All material you need is at your lab station. If you talk or your phone is out you will receive a zero and your paper will be taken and you will fail the course for a violation of academic integrity.

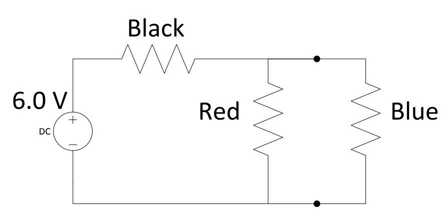
All Diagrams are approximation, your breadboard may not look identical to the diagram but the configuration will be the same.

Set Up 1 – DC Circuits

You have three colored resistors. Use the multimeter to measure the resistance of each one.

Color	R
Black	
Red	
Blue	

Build the circuit shown below on your breadboard.



Use the multimeter to measure the voltage across each, and the current through each.

Color	I	v
Black		
Red		
Blue		

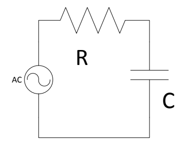
Are the values you obtained for current and voltage in the Red and the Blue what you would expect? Explain your answer.

Show your circuit to your lab instructor before taking it apart.

Circuit Check _________

Set Up 2 – AC circuits

Connect the 12k resistor in series with the capacitor specified on the front board



Connect the signal generator appropriately and set the frequency to 1 kHz

Connect the oscilloscope so as to measure the voltage through the capacitor.
Record the following measurement values

Hit the button labeled cursors to display the cursors

You will need to select which axis cursor you wish to move X or Y. The check mark indicates which one is active, and select which of the two cursors on that axis you want to move using soft keys below screen

Configuration for X1 active cursor, Check mar under X and X1 has highlighted circular arrow

Time for one complete cycle = ____________________________

Frequency as measured on the oscilloscope = _______________

Time Constant, for step response(charging), as measured by the oscilloscope = ____________

DO NOT TURN OFF YOUR CIRCUIT.

Leave your set up on and hand your paper to your lab instructor. Then you are to leave the lab room

	Yes	No
Circuit was connected correctly to signal generator		
Oscilloscope probe was connected correctly		
Screen displayed Capacitor's Voltage		
Screen was appropriately sized		

Appendix E Weekly myDAQ Lab Survey

EE 2010L Weekly Lab Survey

Name & UID: ____

Section Number and TA name:____

Approximately how much total time did you spend on collecting data for your lab this week? That is how long it took you to complete the measurements you were required to perform in the lab activity. Do not include time for your pre-lab or writing your report. (30 minutes, 1 hour, 1.5 hours, etc.)? ____________

Did you collaborate with anyone in the collection of your lab data this week? (Mark all that apply) It is acceptable to collaborate with someone as long you are the one who actually does the measurements with the equipment you were issued. Your lab data should not be identical to anyone else's lab data.

- ☐ No I did not collaborate with anyone
- ☐ I collaborated with another who is in the class
- ☐ I collaborated with another student who completed the class in another term
- ☐ I collaborated with someone from outside Wright State (tutor, friend, family member)
- ☐ I collaborated with one of the tutors for EE 2010
- ☐ I collaborated with my lecture instructor

Approximately how long did you spend on collaboration? __________________________

Please check the following answer which best describes your thoughts on the lab activity this week.

- ☐ It was too difficult the material was not accessible to me
- ☐ Some parts were challenging, but overall not too difficult
- ☐ It was right where it should be, not too difficult but not too easy either
- ☐ It was too easy; I felt my time could have been better used in other ways.

Did you go to open lab this week? Please list how long you spent in open lab if you went

- ☐ No I did not go
- ☐ Yes I went ____ times for about _____ total hours

Appendix F Lab 1 Bench Instructions

Name: ______________________ Lab TA: _____________

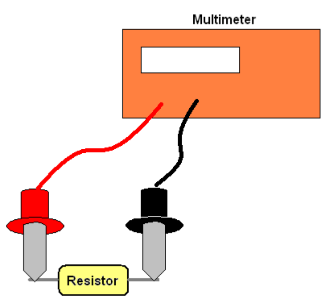
Date Performed: _____________ Date Due: ___________________

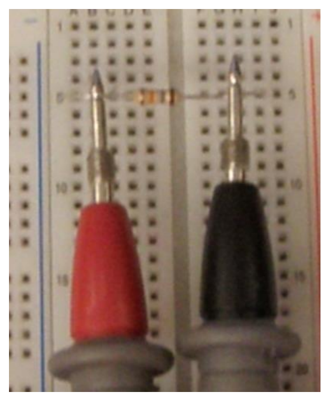
Lab Partner(s):____

EE 2010L Laboratory 1

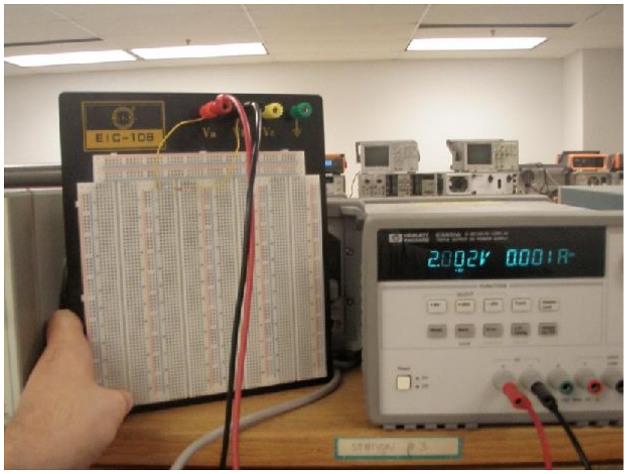
Part 1

1.) Connect a red and black probe to the appropriate 6 V terminals of the power supply.
2.) Using two jumper wires create a connection between the lead terminals on the bread board and the breadboard. Your TA will demonstrate this
3.) Connect the leads from the power supply to the breadboard.
4.) Your TA will give you a Resistor, use the multimeter to measure and record the value of the resistor.



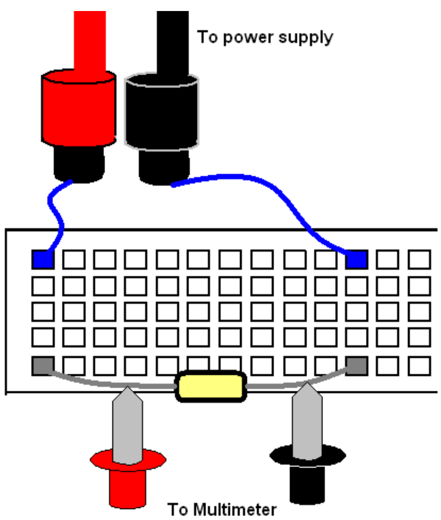


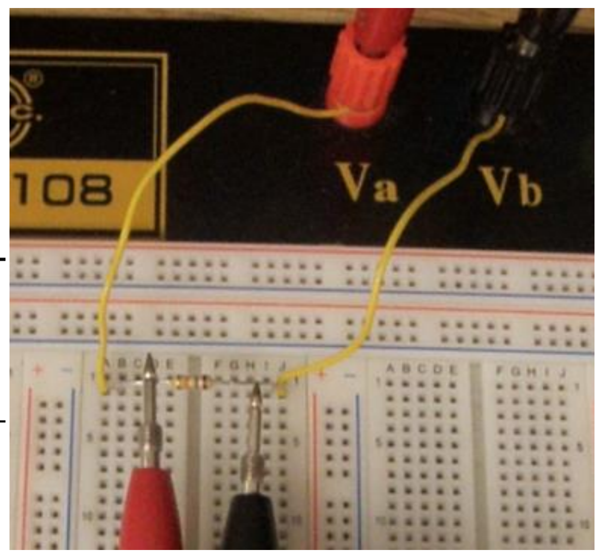
5.) Set the resistor on the breadboard so it is connected to the power supply. The picture below shows this. Note your breadboard does not have to be right next to the power supply. Note the jumper wires connecting the terminals to the breadboard.



Measuring Voltage

1.) Turn on the power supply and set the voltage to 2.0V
2.) Set the leads and the dial of the multimeter to appropriately measure voltage.
3.) Touch the red lead form the multimeter to the side of the resistor connected to the read lead form the power supply (red-to-red). Touch the black lead form the multimeter to the black lead form the power supply (black-to-black)

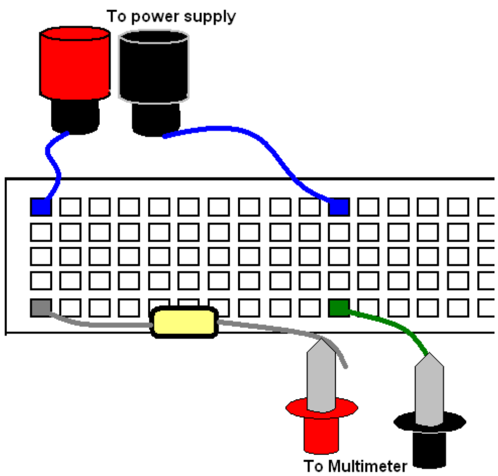


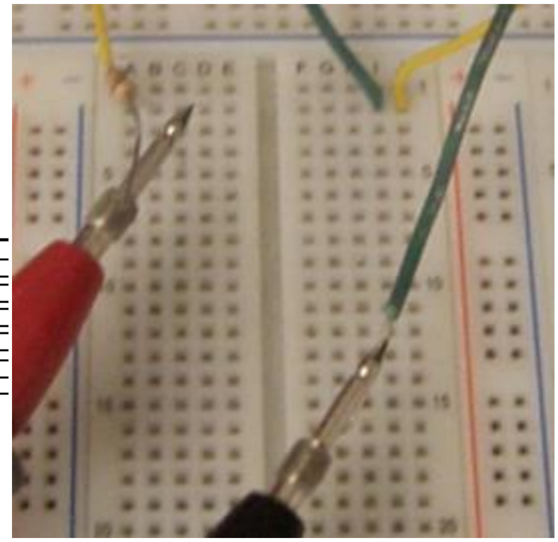


4.) Record the voltage across the resistor, as displayed on the multimeter.

Measuring Current

1.) Select a jumper wire. Remove the end of the resistor connected to the COM terminal of the power supply from the bread board. Insert the jumper wire into the whole from which you removed the resistor.
2.) Set the multimeter appropriately to measure current.(hint your current will be in milliamps)
3.) Connect the red probe of the multimeter to the resistor and the black probe of the multimeter to the jumper wire Record the current.





Part 2

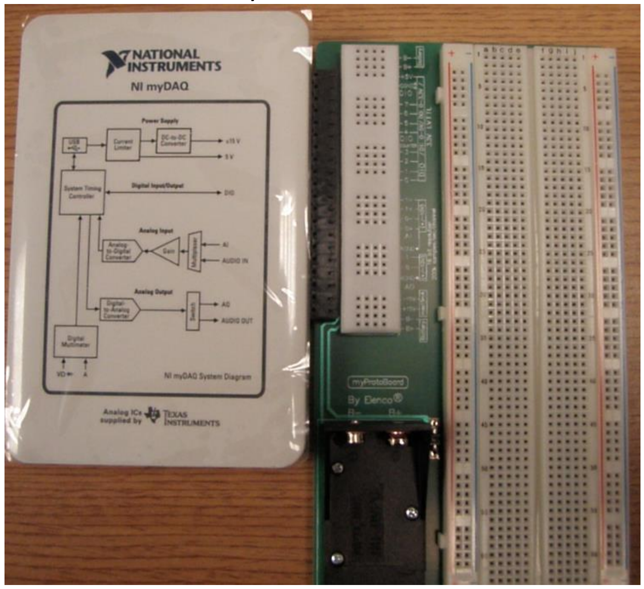
Repeat Part 1 using a different resistor. You will measure the resistance of the resistor, the voltage across when connected to a 2.00V power supply and the current through when connected to the same power supply.

For Your lab report

1.) Use Ohms law and the measured to resistance and voltage to determine what current you should have theoretically measured.
2.) Calculate a percent difference between the measured current and predicted current
3.) Explain what would have happened to your measurements if you had accidently flipped the leads to the multimeter. (I.e. if you had connected red to black instead of red to red)

Appendix G Lab 1 myDAQ Instructions

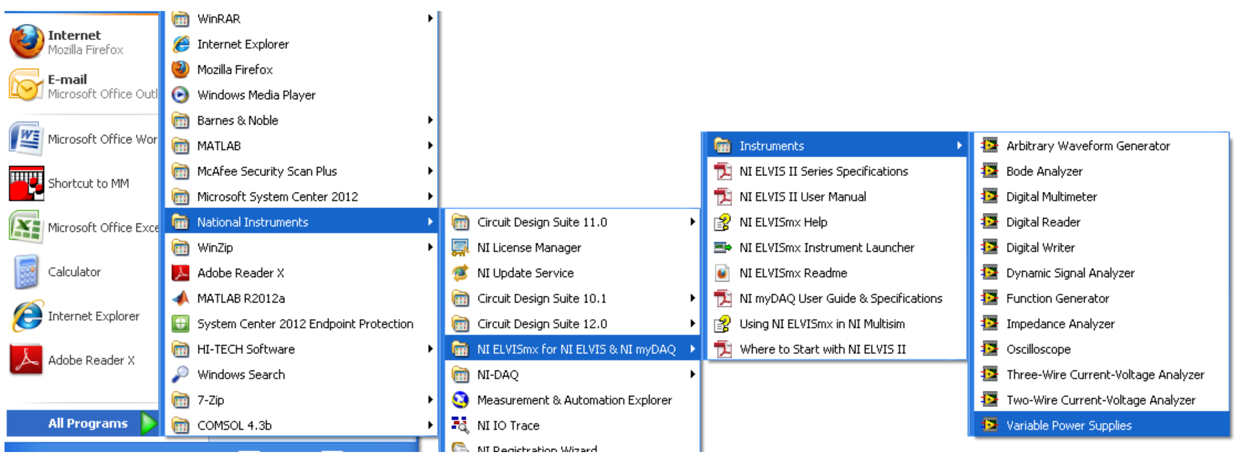
1.) Align & Plug the protoboard into the myDAQ



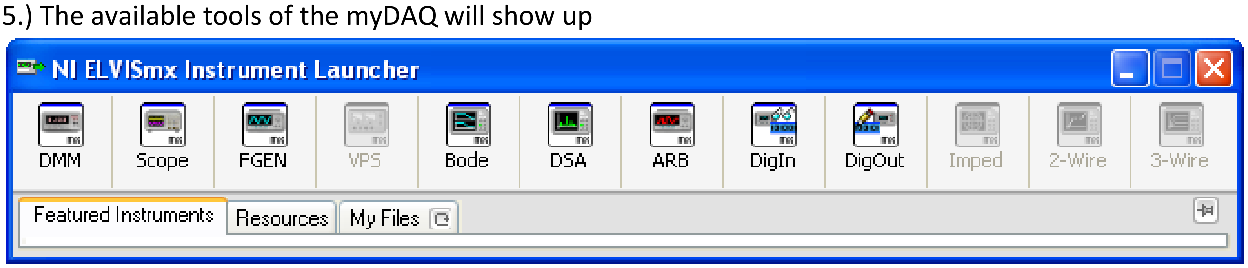
2.) Plug the myDAQ into the USB Drive

3.) Your computer will find the new hardware

4.) Once the device is found you will want to open the NI ELVISmx Instrument Launcher



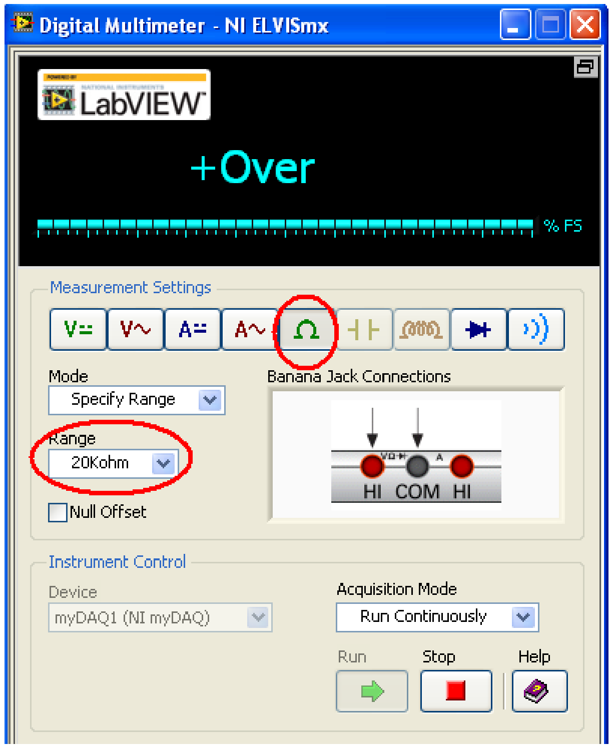
5.) The available tools of the myDAQ will show up



Those instruments in color are available for use.

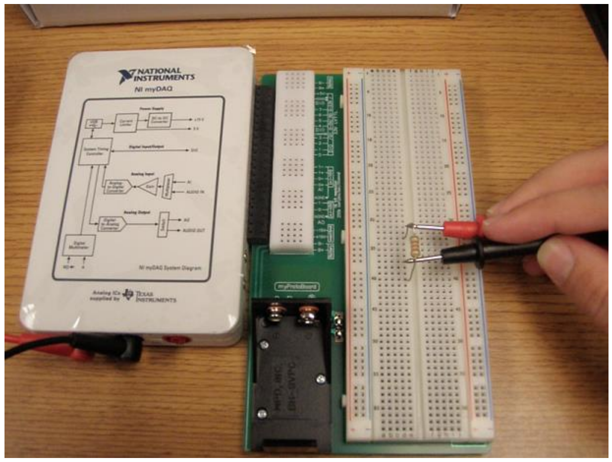
Measuring Resistance

1.) Open the DMM (Digital Multi-Meter). Select the Omega (Ω) this tells the DMM we want to measure resistance. Set the Range to 20Kohm. The DMM will not measure resistance if there is power running to the circuit



2.) If you notice the DMM shows you where to connect the probe leads.

3.) Pick a resistor that is 2.0 kΩ or larger and place the resistor on the breadboard and touch the probe leads to either side.



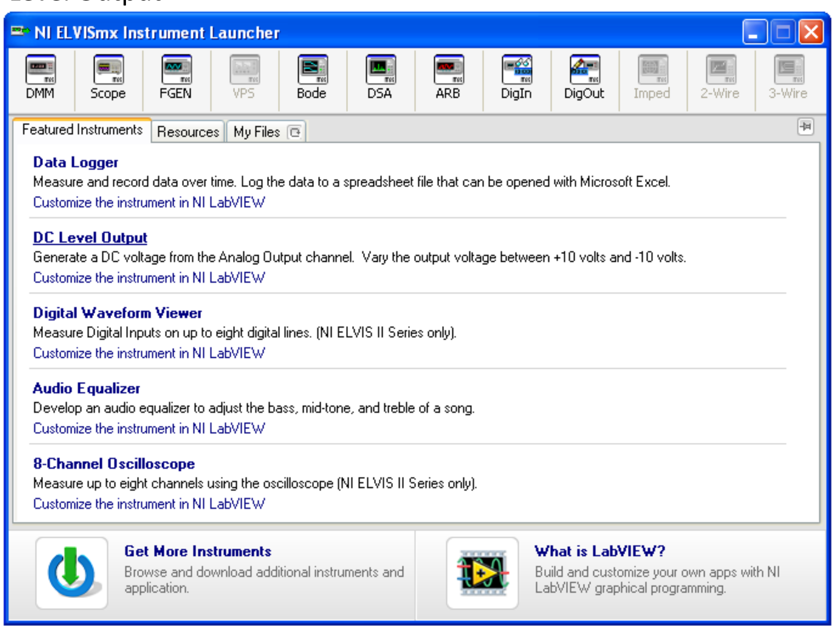
4.) This DMM will display the resistance.

Measuring Voltage

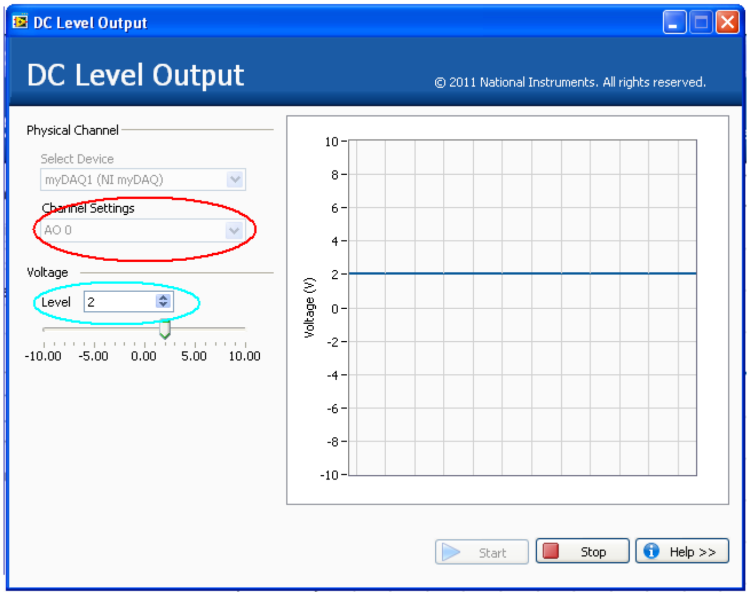
1.) Open the DMM and

2.) From the instrument launcher select “Featured Instruments” A drop down menu will appear

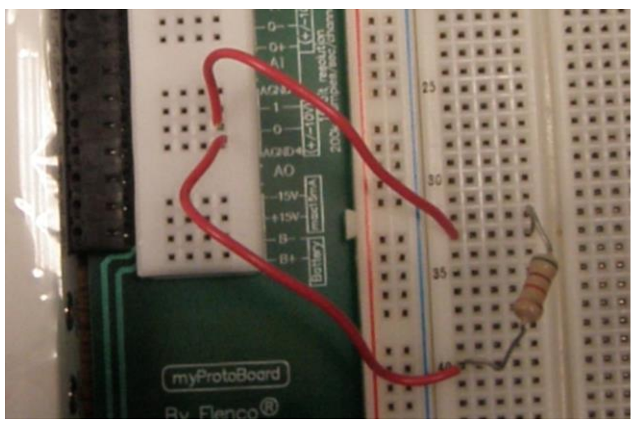
3.) Select “DC Level Output”



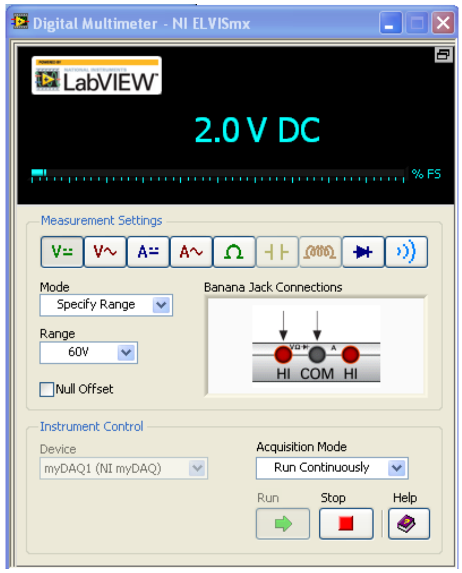
4.) You can set the DC level output. And select the output terminal. Typically we will use “AO 0”. The Level is what voltage you want. For this example set it to 2.0



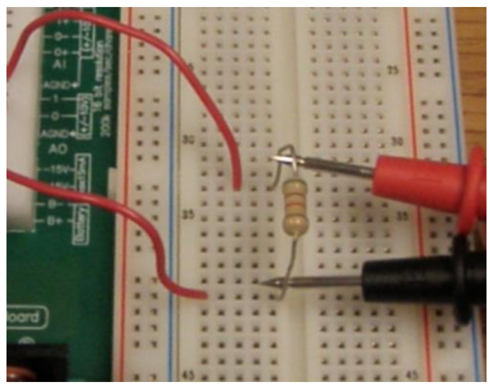
5.) Connect two jumper wires form the source to the breadboard. Notice we have them at AO 0 and GRD. AO stands for analog output the myDAQ has two analog outputs, they are labeled as 0 and 1



6.) Connect the resistor to the breadboard as shown above.
7.) Click start on the DC level output. You have now supplied power to the resistor on the breadboard.
8.) On the DMM set it to measure voltage (the green V with the solid line). Click the run arrow.



9.) Hold the probe leads on either side of the resistor.

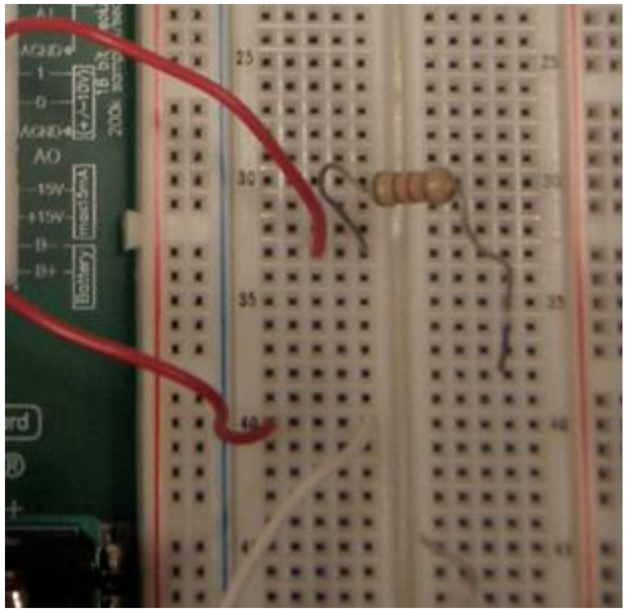


10.) Your DMM should say 2.0V as in the picture above.

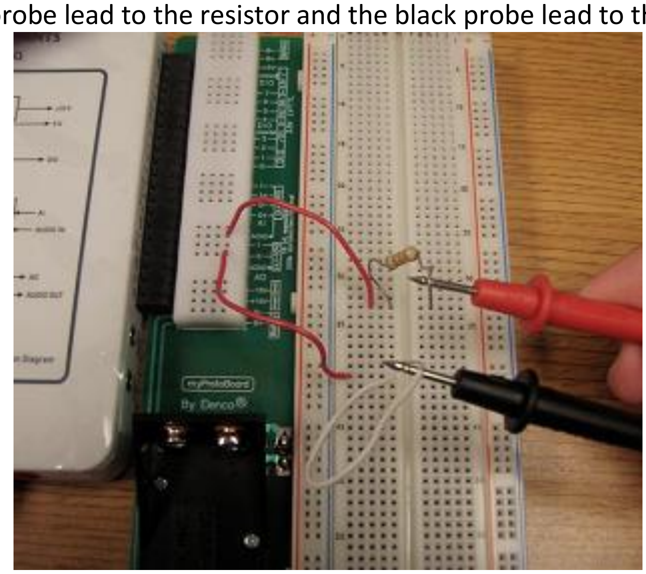
Measuring Current

1.) Set the DMM to measure current, the blue A with the solid lines. Notice the DMM shows you need to move the probe leads on the myDAQ.

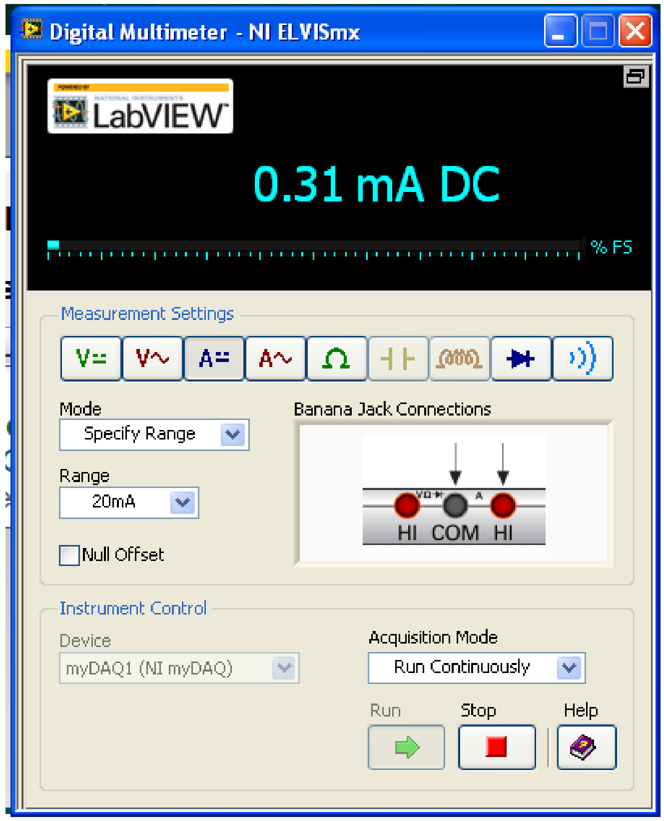
2.) On the breadboard remove the side of the resistor connected to ground. Place a jumper wire on the breadboard in the hole that you removed the resistor from. Notice the white jumper wire on the image below.



3.) Connect the red probe lead to the resistor and the black probe lead to the wire.



4.) The DMM will now display the current.



Now repeat all parts for the second resistor

For Your lab report

1.) Use Ohms law and the measured to resistance and voltage to determine what current you should have theoretically measured.
2.) Calculate a percent difference between the measured current and predicted current
3.) Explain what would have happened to your measurements if you had accidently flipped the leads to the multimeter. (I.e. if you had connected red to black instead of red to red)

Appendix H Lab 2 Bench Instructions
Name: ______________________ Lab TA: _____________

Date Performed: _____________ Date Due: ____________________

Lab Partner:______________________________

EE 2010 Laboratory 2

Getting Started:

Building a simple circuit with real components

The purpose of this laboratory is to become acquainted with real components, the lab equipment and learn how to use these items properly.

You will use the following concepts covered in the first week's lab:

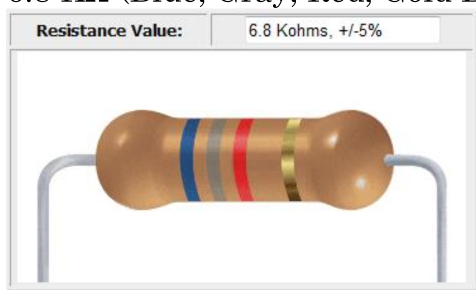
- How to place components on the breadboard, noting interconnectivity;
- How to generate a DC voltage with the power supply;
- How to measure the voltage across a circuit using a voltmeter;
- How to identify the value of a resistor through its color code;
- How to measure the value of a resistor with an ohmmeter;
- How to construct and analyze a circuit using real components.

Finally, ask your lab instructor to discuss safety issues regarding the lab equipment. While none of the equipment is particularly dangerous, if used correctly, any instrument can produce unexpected results if misused, so it always pays to avoid doing so.

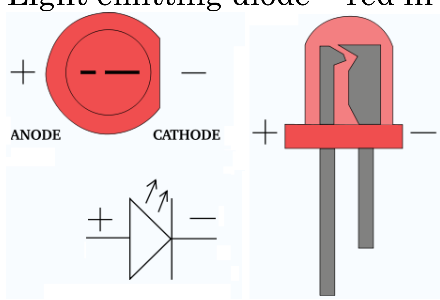
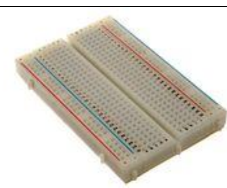
It is very important to maintain a CLEAN FACILITY, so please clean your area before you leave the laboratory.

You will be provided all the components needed for this lab at your work bench.

You should receive the following components. Your TA will help you locate and use the components to construct a working circuit from the schematic diagram found later in this document.

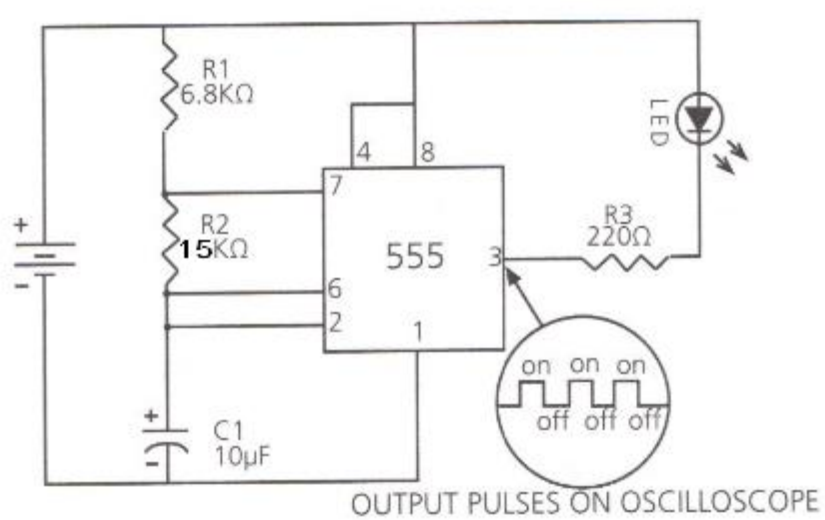
Component	Description
Resistor #1	6.8 KΩ (Blue, Gray, Red, Gold Bands) 
Resistor #2	15 KΩ (Brown, Green, Orange, Gold Bands) 
Resistor #3	220 Ω (Red, Red, Brown, Gold) 

Capacitor #1	10 μF

	
555 IC Timer	NE555N integrated circuit 
RED LED	Light emitting diode – red in color 
Breadboard	
Voltage supply	

In Lab Tasks:

1. Construct the circuit on the breadboard using the electronic schematic below.
2. Use 9 volts DC for the voltage source.
3. Use the multimeter and measure the voltage drops across each of the three resistors.
4. Record the voltages.
5. Use the multimeter and measure the actual resistance of each of the three resistors.
6. Record the resistance values.
7. Demonstrate the functional circuit to your TA.
8. Once the TA has approved your work, remove all the components from the breadboard, return them to the proper locations, and clean up the work area.
9. Write the lab report and submit to the proper location.



For Your Lab Report

1. Answer the questions below in your lab report.
2. Make a table of the estimate resistor values based on the color bands, the measured voltage drops, the measured resistance values, and the percent difference between estimated resistance and actual resistance values. Be sure to include units as part of your table.

Questions for the lab report

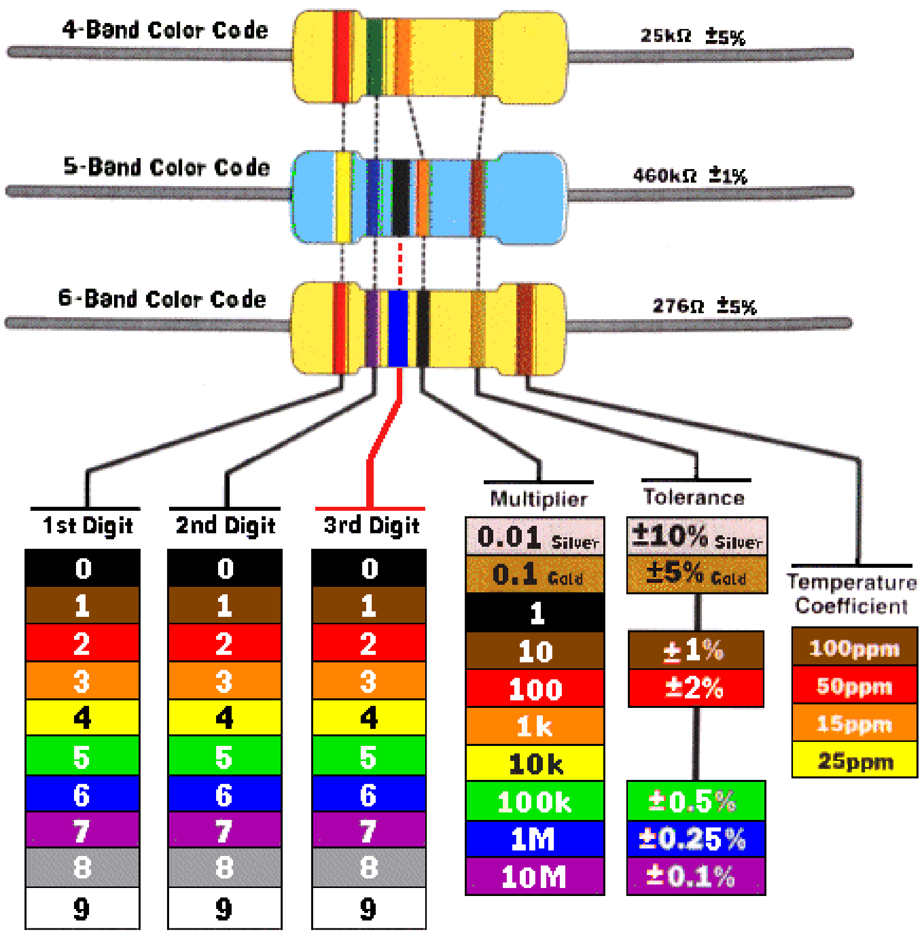
1. Are there any appreciable differences between labeled, calculated, and measured values for the two resistances? What could possibly explain the disparity?

2. What do you believe would happen, if you removed the 220 ohm resistor from the circuit and connected the LED directly to the 555 integrated circuit?

3. Give an explanation for why the LED is flashing and not continuously on.

Additional resources for the lab

This is a chart to help estimate the expected resistance.



Appendix I Lab 2 myDAQ instructions

Name: ______________________ Lab TA: _____________

Date Performed: _____________ Date Due: ___________________

Lab Partner(s):____

EE 2010 Laboratory 2

Getting Started:

Building a simple circuit with real components

The purpose of this laboratory is to become acquainted with real components, the lab equipment and learn how to use these items properly.

You will use the following concepts covered in the first week's lab:

- How to place components on the breadboard, noting interconnectivity;
- How to generate a DC voltage with the power supply;
- How to measure the voltage across a circuit using a voltmeter;
- How to identify the value of a resistor through its color code;
- How to measure the value of a resistor with an ohmmeter;
- How to construct and analyze a circuit using real components.

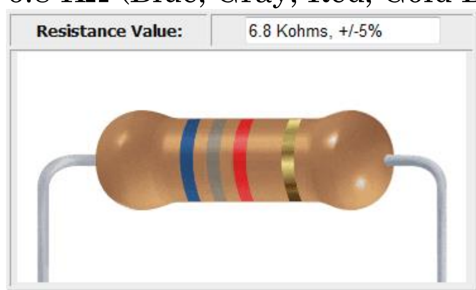
Finally, ask your lab instructor to discuss safety issues regarding the lab equipment. While none of the equipment is particularly dangerous, if used correctly, any instrument can produce unexpected results if misused, so it always pays to avoid doing so.

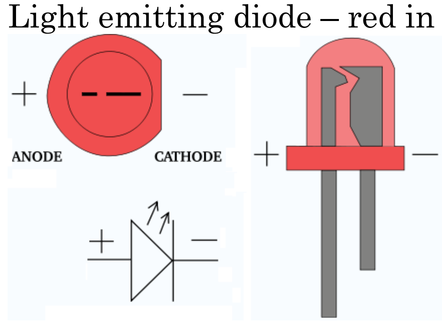
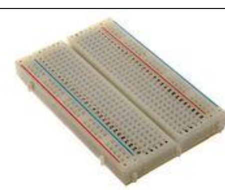
It is very important to maintain a CLEAN FACILITY, so please clean your area before you leave the laboratory.

Lab Activity

You will be provided all the components needed for this lab at your work bench.

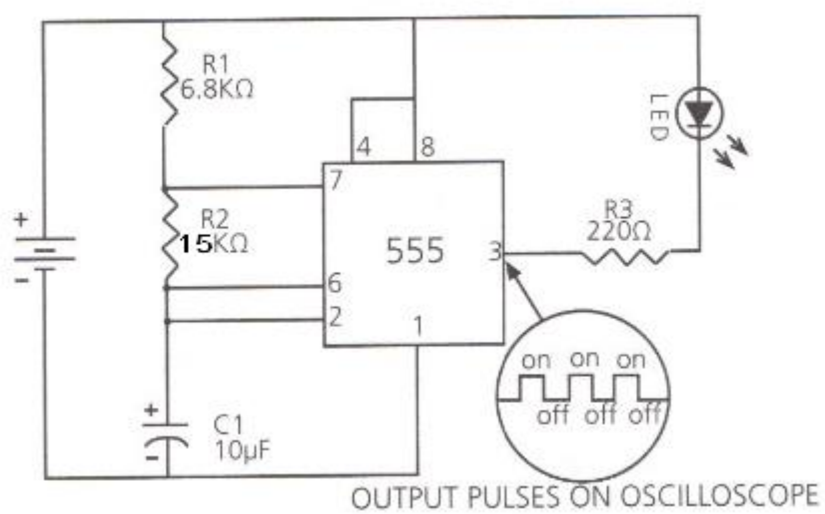
You should receive the following components. Your TA will help you locate and use the components to construct a working circuit from the schematic diagram found later in this document.

Component	Description
Resistor #1	6.8 KΩ (Blue, Gray, Red, Gold Bands) 
Resistor #2	15 KΩ (Brown, Green, Orange, Gold Bands) 
Resistor #3	220 Ω (Red, Red, Brown, Gold) 

Capacitor #1	10 μF 
555 IC Timer	NE555N integrated circuit 
RED LED	Light emitting diode – red in color 
Breadboard	
Voltage supply	

In Lab Tasks:

10. Construct the circuit on the breadboard using the electronic schematic below.
11. Use 9 volts DC for the voltage source.
12. Use the multimeter and measure the voltage drops across each of the three resistors.
13. Record the voltages.
14. Use the multimeter and measure the actual resistance of each of the three resistors.
15. Record the resistance values.
16. Demonstrate the functional circuit to your TA.
17. Once the TA has approved your work, remove all the components from the breadboard, return them to the proper locations, and clean up the work area.
18. Write the lab report and submit to the proper location.



For Your Lab Report

3. Answer the questions below in your lab report.
4. Make a table of the estimate resistor values based on the color bands, the measured voltage drops, the measured resistance values, and the percent difference between estimated resistance and actual resistance values. Be sure to include units as part of your table.

Questions for the lab report

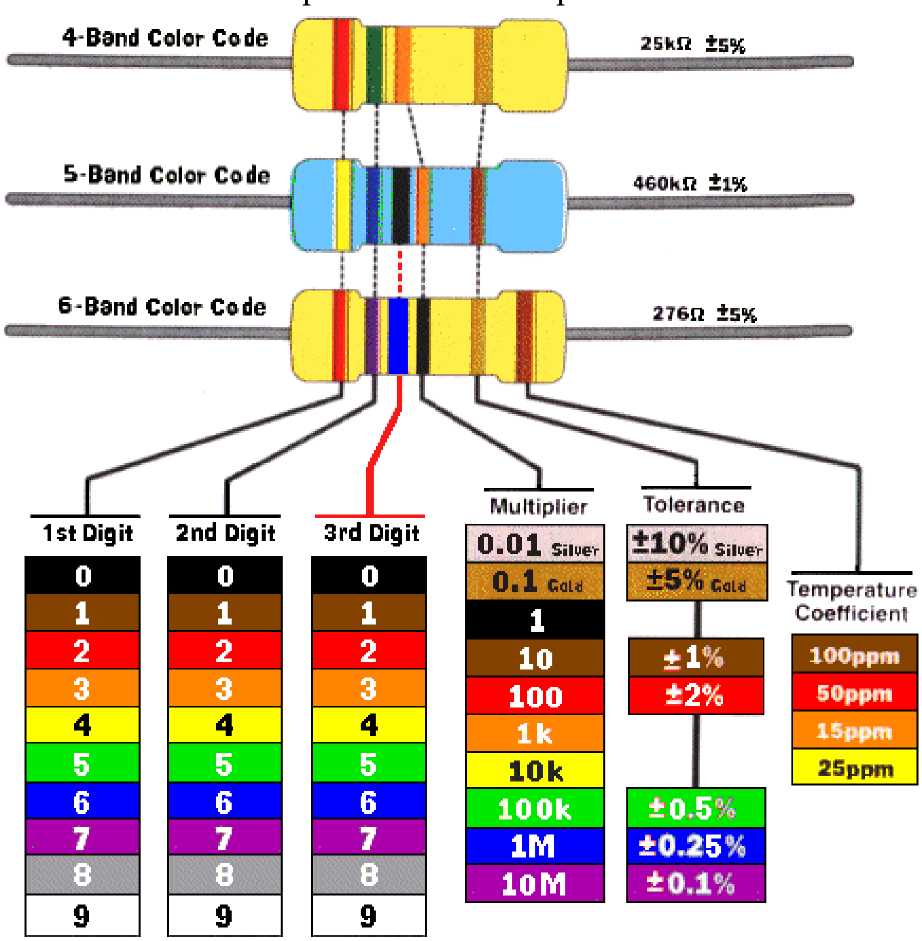
4. Are there any appreciable differences between labeled, calculated, and measured values for the two resistances? What could possibly explain the disparity?

5. What do you believe would happen, if you removed the 220 ohm resistor from the circuit and connected the LED directly to the 555 integrated circuit?

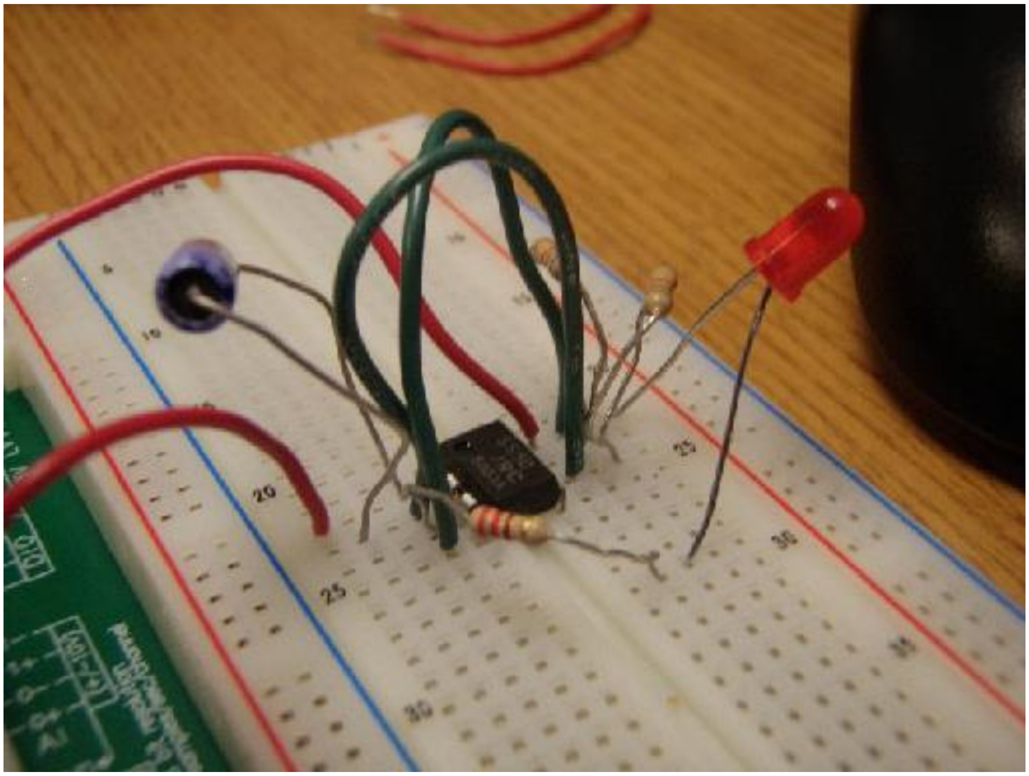
6. Give an explanation for why the LED is flashing and not continuously on.

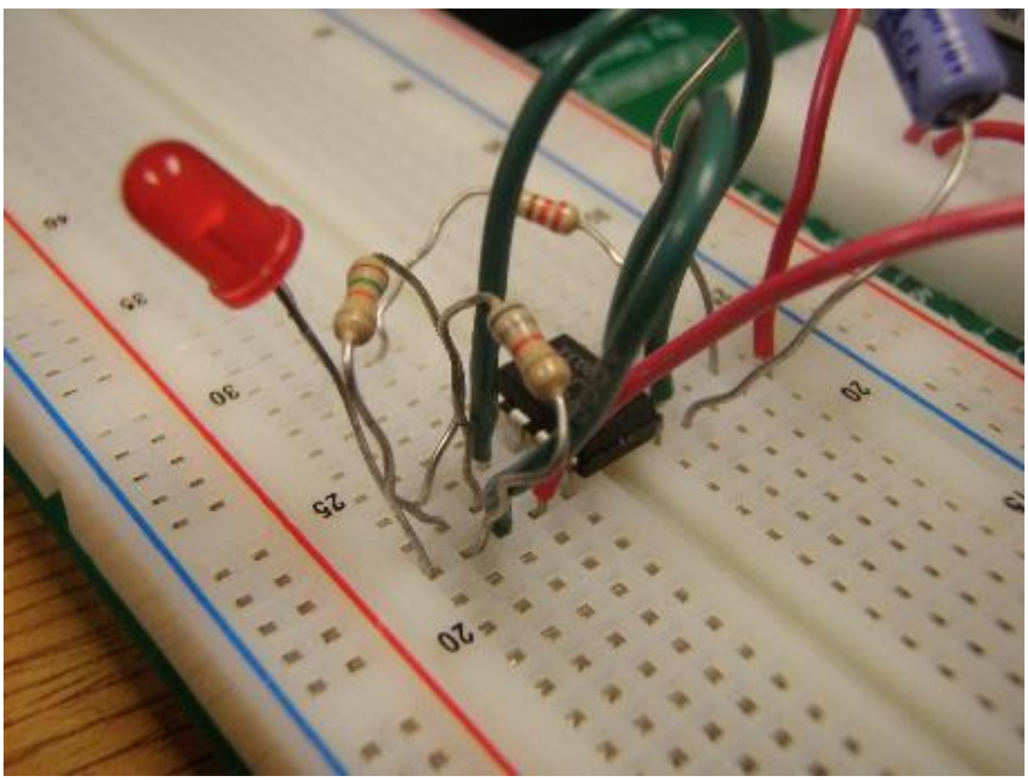
Additional resources for the lab

This is a chart to help estimate the expected resistance.



Below are some pictures of the circuit set up on the protoboard





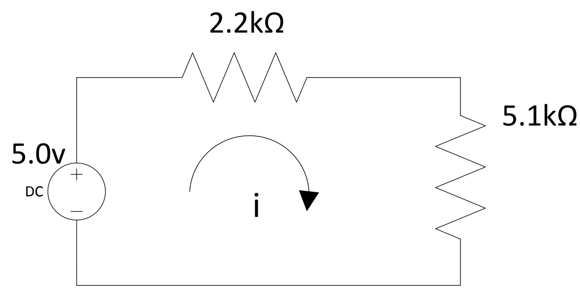
Appendix J Lab 3 Instructions
Name:________________ Lab TA:_______________
Date Performed:________________ Date Due:_________________
Lab Partner(s): ____

EE 2010L Laboratory 3

Voltage, Current, Resistance, and Ohm's Law

The purpose of this laboratory is to practice making voltage, current, and resistance measurements and become acquainted with Ohm's Law. There are two different configurations of the circuit you will build. The first is a series circuit. The second is a parallel circuit. You are to observe the difference in voltage drops and total resistances in each case.

PART A: Please refer to the following circuit. **This is the series configuration.**



1. Build the circuit as shown. Use your regulated power supply to generate 5.0 V and connect it to the 2.2 kΩ and 5.1 kΩ resistors as indicated. You should only use the two resistors and two wires connecting the breadboard to the power supply. **Measure the voltage across each resistor and the current through each resistor** (Hint: make sure your multimeter 's leads are connected properly for a given measurement).

   $V_{2.2\ k\Omega}$ = __________
   $V_{5.1\ k\Omega}$ = __________
   $I_{2.2\ k\Omega}$ = __________
   $I_{5.1\ k\Omega}$ = __________

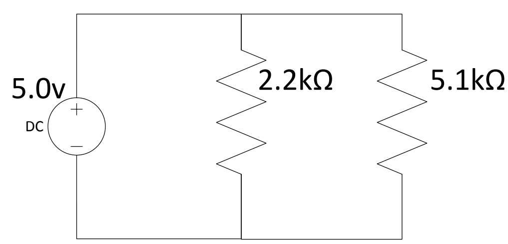
2. Using the values you just measured, calculate the theoretical resistance of each resistor by Ohm's Law. $v = iR$

$R_{2.2\text{ k}\Omega} = V_{2.2\text{ k}\Omega} / I =$ __________
$R_{5.1\text{ k}\Omega} = V_{5.1\text{ k}\Omega} / I =$ __________

3. Now, measure the actual resistance of <u>each resistor</u> and the <u>total resistance of the two resistors</u> using your multimeter.

   $R_{2.2\text{ k}\Omega\text{ (actual)}} =$ __________
   $R_{5.1\text{ k}\Omega\text{ (actual)}} =$ __________
   R_{Total} (actual) = ____________

PART B: Please refer to the following circuit. **This is the parallel configuration.**



4. Build the circuit as shown above. You should only use the two resistors and two wires connecting the breadboard to the power supply. Then, use your regulated power supply to generate 5 V and connect it to the 2.2 kΩ and 5.1 kΩ resistors as indicated. **Measure the voltages across each resistor and the current through the circuit** (hint: make sure your multimeter 's leads are connected properly for a given measurement).

   $V_{2.2\text{ k}\Omega} =$ __________
   $V_{5.1\text{ k}\Omega} =$ __________
   $I_{2.2\text{ k}\Omega} =$ __________
   $I_{5.1\text{ k}\Omega} =$ __________

5. Using the values you just measured, calculate the theoretical resistance of each resistor by Ohm's Law. $v = iR$

   $R_{2.2\text{ k}\Omega} = V_{2.2\text{ k}\Omega} / I =$ __________
   $R_{5.1\text{ k}\Omega} = V_{5.1\text{ k}\Omega} / I =$ __________

6. Now, measure the actual resistance of each resistor and the total resistance using your multimeter.

   $R_{2.2\ k\Omega\ (actual)}$ = ___________
   $R_{5.1\ k\Omega\ (actual)}$ = ___________
   R_{Total} (actual) = _____________

For Your Lab Report

5. Answer the questions below in your lab report.
6. Make a table for each circuit configurations showing the current through each resistor, the measured voltage across each resistor, the calculated voltage across each resistor form the pre-lab and the percent difference.

7. In your conclusion make a statement about how voltage is related across resistors in series and parallel. Also make a statement about the relation of current between resistors in series and in parallel

QUESTIONS

1. How is the voltage across the two resistors in series related to the voltage of the source? How is the voltage across the two resistors in parallel related to the source voltage?

2. How is the current across the two resistors in parallel related? How is the current across the two resistors in series related to the size of the resistor?

3. What do you notice about the total resistances of each configuration?

4. Why must you measure the current differently than you measure the voltage? (That is why is voltage measurement done by simply placing the leads across the resistor and why is current measured by breaking the circuit and inserting the leads of the DMM?)

Appendix K Lab 4 Bench Instructions

Name:____________________ Lab TA:___________________

Date Performed:____________________ Date Due:___________________

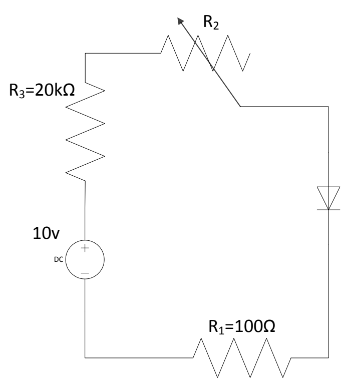
Lab Partner(s): ____

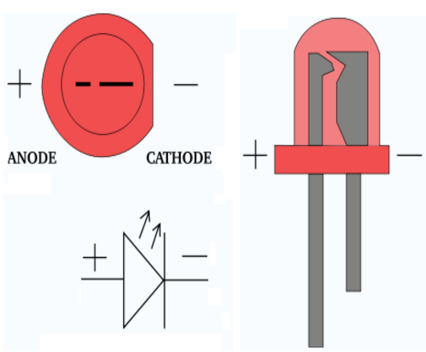
The purpose of this laboratory is to practice making combination types of circuits. Also, you will reinforce your previous understanding of voltage, current, and resistance measurements. This will improve your understanding of Ohm's Law.

There are two different circuits for you to build. You will use basic instrumentation to obtain required measurements. You are to observe the difference in voltage drops and total resistances in each case.

<u>Part A: Using a potentiometer in a simple circuit.</u>

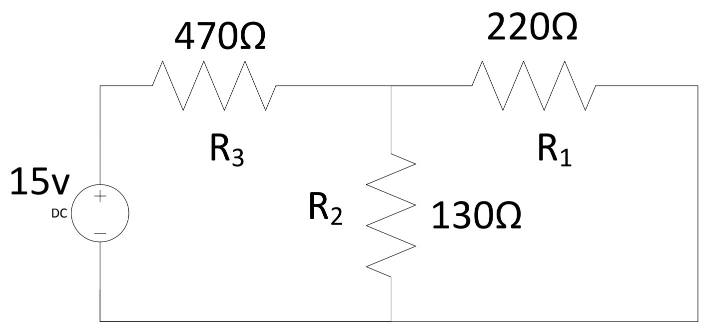
1. We will use terminals 1 and 2 as connection points for this lab. Use the multimeter to set the resistance of the potentiometer to 10kΩ
2. Construct the circuit shown below using the information you obtained from your Prelab 4 work. Use a 10 volt source, R_1 is a 100 ohm resistor.
3. Slowly adjust the value of the potentiometer until the LED just begins to turn on
4. Demonstrate the proper function of the circuit to the Teaching Assistant.
5. Measure and record the resistance of the potentiometer when the LED just turns on





Part B: Constructing a simple combination circuit.

1. Construct the circuit shown below using the information you obtained from your Prelab 4 work. You should know the 'color bands' for the resistors needed for this activity.



2. **Obtain the following measurements:**
   A. V_{R1} (measure the voltage drop across resistor R1)
   B. V_{R2} (measure the voltage drop across resistor R2)
   C. V_{R3} (measure the voltage drop across resistor R3)
   D. I_{R1} (measure the current through resistor R1)
   E. I_{R2} (measure the current through resistor R2)
   F. I_{R3} (measure the current through resistor R3)

For your lab report

Table for part one showing the voltage across R_1 when LED goes out and the value of the resistance of the potentiometer

A table for all the value in Part B, also include in the table a calculated current for each resistor based on ohms law and the measured voltage drop across each resistor. Do a percent difference between the measured current and calculated current you found in the pre-lab.

Answer the following questions

1. If a potentiometer has a maximum resistance of 100k. If the potentiometer is measured at 25k when connected to terminals 1 and 2 what value would you expect when connected to 2 and 3?

2. In part B how is the voltage in R_1 and R_2 related? Is this result what you would expect, explain your answer?

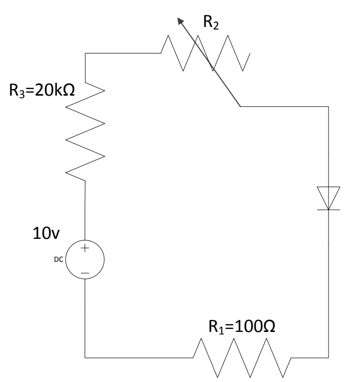
Appendix L Lab 4 myDAQ Instructions
Name:____________________ Lab TA:___________________
Date Performed:____________________ Date Due:___________________
Lab Partner(s): ____

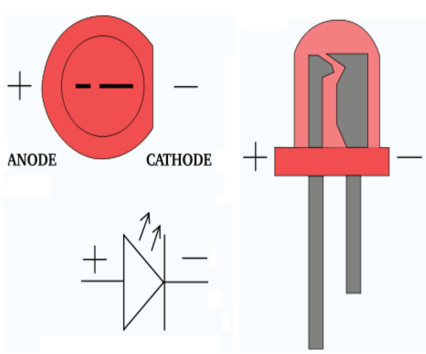
The purpose of this laboratory is to practice making combination types of circuits. Also, you will reinforce your previous understanding of voltage, current, and resistance measurements. This will improve your understanding of Ohm's Law.

There are two different circuits for you to build. You will use basic instrumentation to obtain required measurements. You are to observe the difference in voltage drops and total resistances in each case.

Part A: Using a potentiometer in a simple circuit.

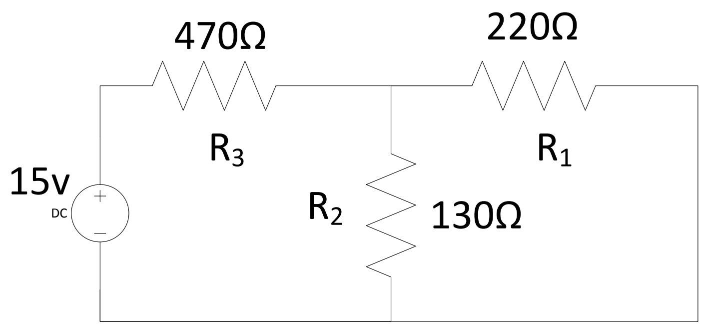
6. We will use terminals 1 and 2 as connection points for this lab. Use the multimeter to set the resistance of the potentiometer to 10kΩ
7. Construct the circuit shown below using the information you obtained from your Prelab 4 work. Use a 10 volt source, R_1 is a 100 ohm resistor.
8. Slowly adjust the value of the potentiometer until the LED just begins to turn on
9. Demonstrate the proper function of the circuit to the Teaching Assistant.
10. Measure and record the resistance of the potentiometer when the LED just turns on



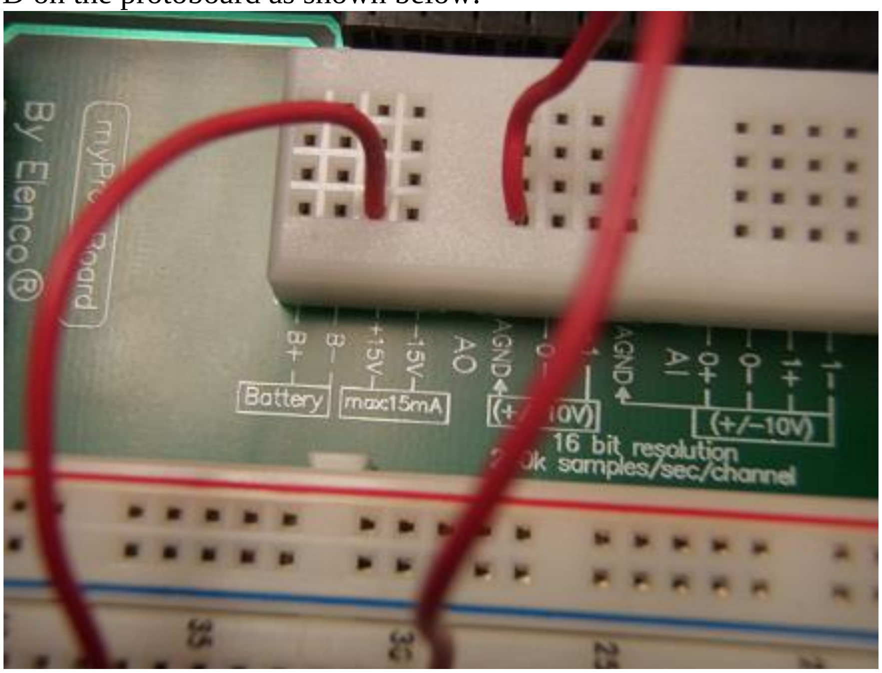


Part B: Constructing a simple combination circuit.

3. Construct the circuit shown below using the information you obtained from your Prelab 4 work. You should know the 'color bands' for the resistors needed for this activity.



To obtain 15V with the myDAQ all we need to do is connect to the +15V and AGRND on the protoboard as shown below.



4. **Obtain the following measurements:**
   - G. V_{R1} (measure the voltage drop across resistor R1)
   - H. V_{R2} (measure the voltage drop across resistor R2)
   - I. V_{R3} (measure the voltage drop across resistor R3)
   - J. I_{R1} (measure the current through resistor R1)
   - K. I_{R2} (measure the current through resistor R2)
   - L. I_{R3} (measure the current through resistor R3)

For your lab report

Table for part one showing the voltage across R_1 when LED goes out and the value of the resistance of the potentiometer

A table for all the value in Part B, also include in the table a calculated current for each resistor based on ohms law and the measured voltage drop across each resistor. Do a percent difference between the measured current and calculated current you found in the pre-lab.

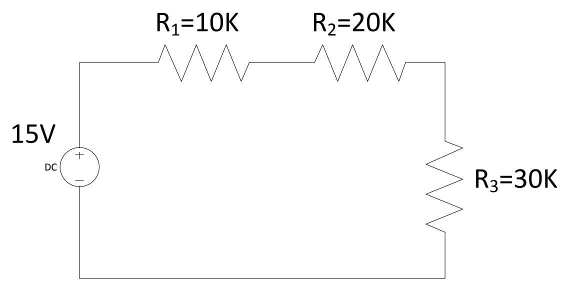
Answer the following questions

1. If a potentiometer has a maximum resistance of 100k. If the potentiometer is measured at 25k when connected to terminals 1 and 2 what value would you expect when connected to 2 and 3?
2. In part B how is the voltage in R_1 and R_2 related? Is this result what you would expect, explain your answer?

Appendix M Lab 5 Instructions
Name: ____________________ Lab TA: ___________________
Date Performed: ____________________ Date Due: _________________
Lab Partner(s): ____

The purpose of this laboratory is to practice voltage division and current division theory. Also, you will reinforce your previous understanding of voltage, current, and resistance measurements.

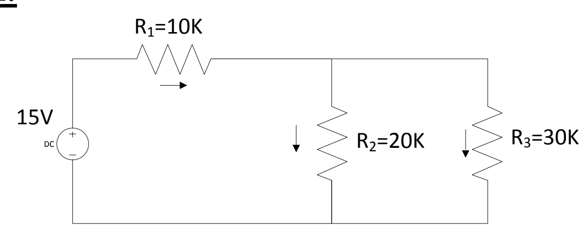
1 - Voltage Division:



Build the voltage diver circuit from the pre-lab
(a) Measure potential and current in each resistor
V_1 =
V_2 =
V_3 =
I_1 =
I_2 =
I_3 =

(b) Which of **Kirchhoff's law**s does the circuit shown in figure 1 satisfy? Show your work. Explain in detail all likely causes of discrepancy.

2 – Current Division:



Build the current divider circuit from the pre-lab
(a) Measure potential and current in each resistor
V_1 =
V_2 =
V_3 =

I_1 =
I_2 =
I_3 =

(b) R_3 is our load resistor. Remove R_3 from the current divider circuit and measure the potential and current for R_2
V_2 (without loading) =
I_2 (without loading) =
(b) Now, replace R3 with a 100 kΩ resistor in parallel with the resistor R_2 and measure the voltage and current for R2.
V_2 (with load resistance of 100 kΩ) =
I_2 (with load resistance of 100 kΩ) =
(c) Remove the 100 kΩ resistor and connect a 1 MΩ resistor in parallel with R_2; and measure the voltage and current for R_2.
V_2 (with load resistance of 1 MΩ) =
I_2 (with load resistance of 1 MΩ) =

For your lab report:
Construct tables showing all your data. Include appropriate units, and a percent difference for all values measured and calculated in the pre-lab.
Answer the following questions
How do you account for the difference between the calculated values and the measured values?

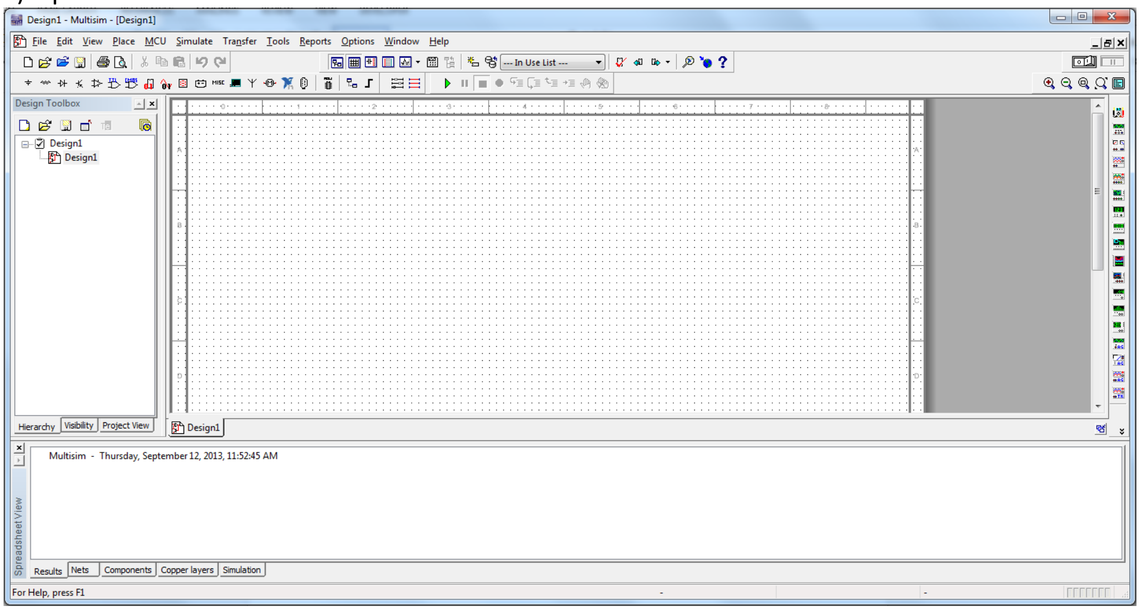
Describe the affect of the load on the current divider circuit.

Appendix N Lab 6 Multisim Instructions

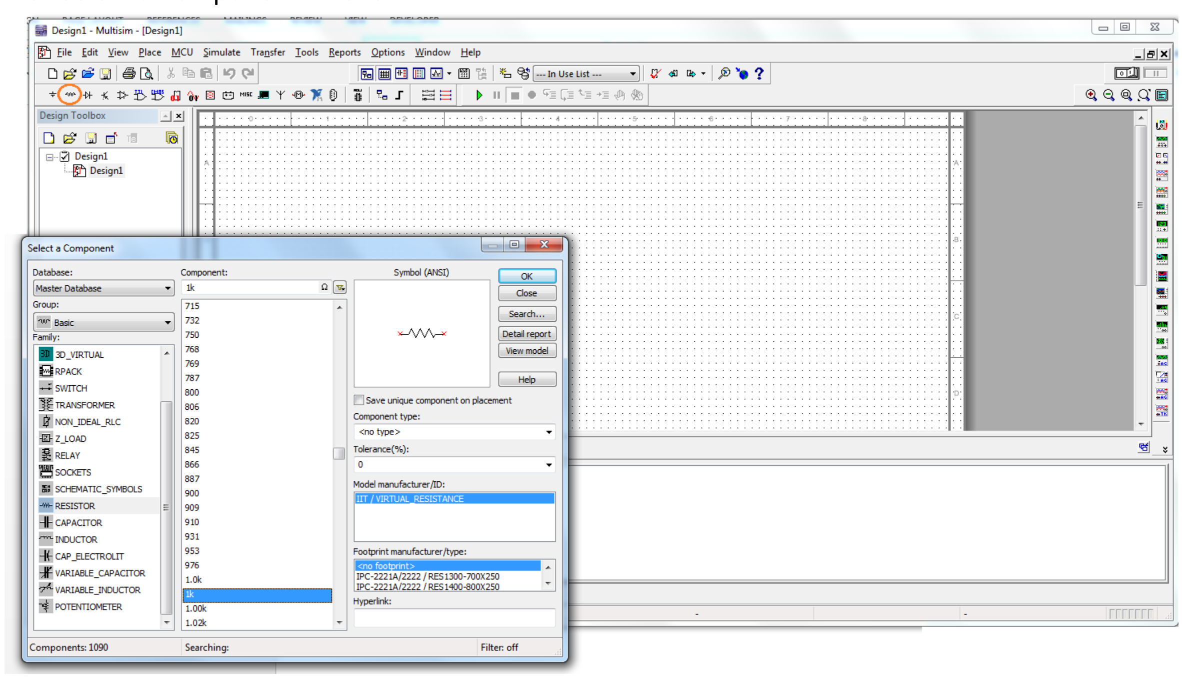
Lab 6

Using Multisim to run a simulation

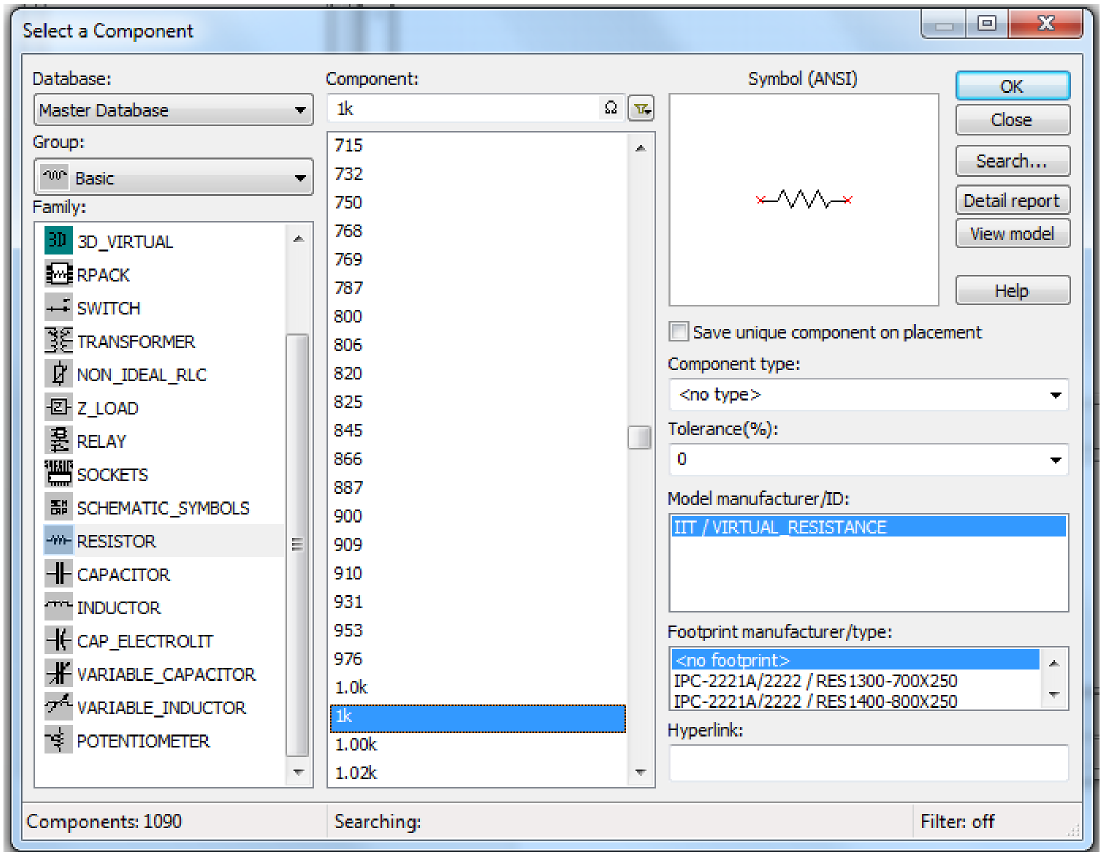
1.) Open Multisim 12.0 from the Start Menu



2.) You will see the design layout and the toolbars. Double click on the resistor. This will open the “Select a Component” menu

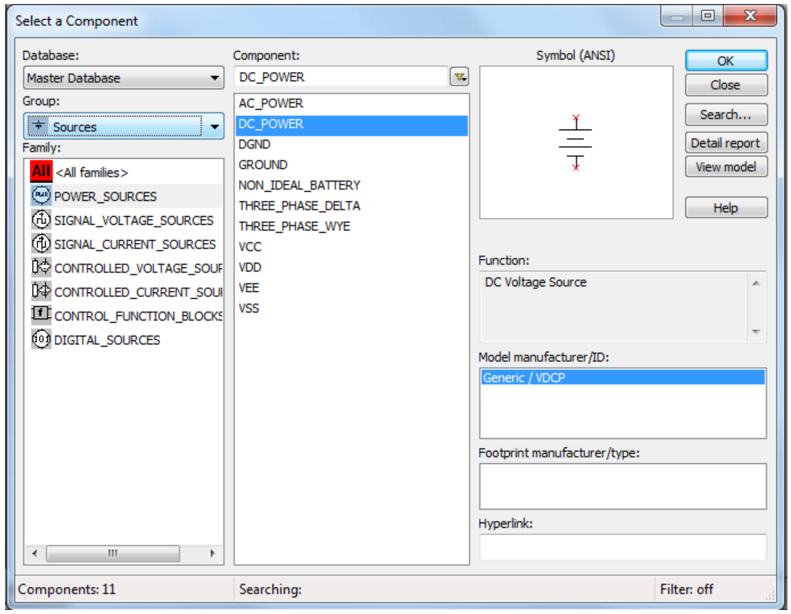


3.) Under the “Family” box on the left select resistor. Under the components box in the middle select “1K”

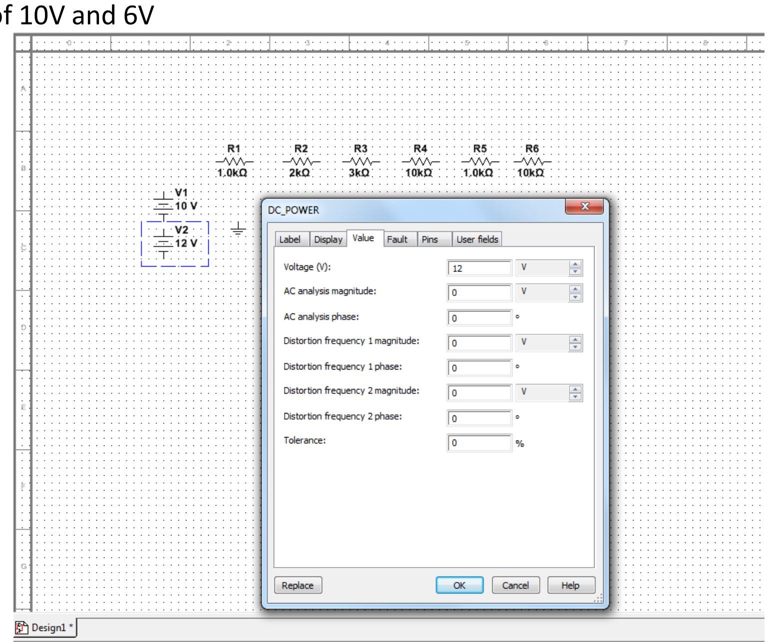


4.) Click OK and this will add the 1K resistor to your design. Left click to place the resistor on the Design. Once you do the “Select a Component” box will reappear. Add all the required resistors to the design. We are just adding them for now we will worry about arranging them in specific place sin a minute.

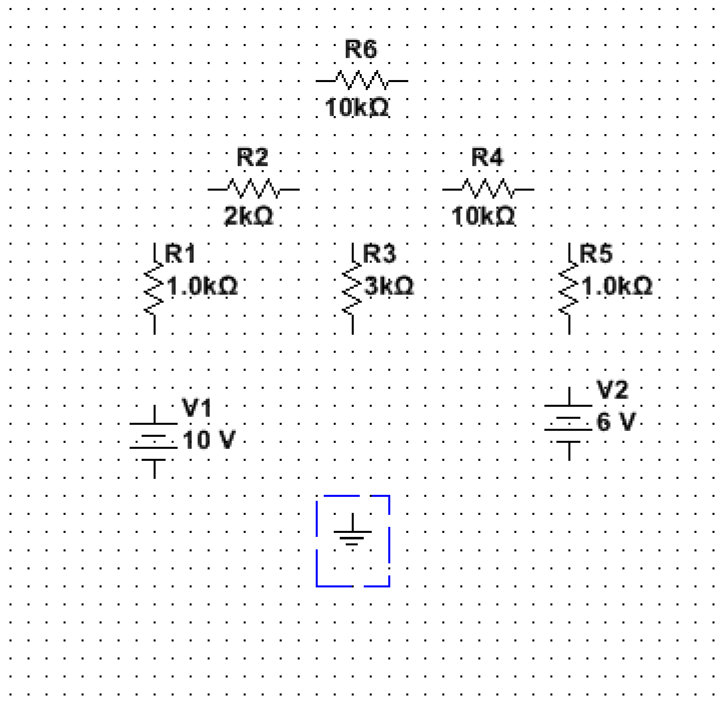
5.) After you have added all the resistors when the “Select a Component pops up change the “Group” to Sources. Under the “Family” menu select “POWER_SOURCES” Under the “Component” menu select “DC_POWER”. Add two DC sources and a ground



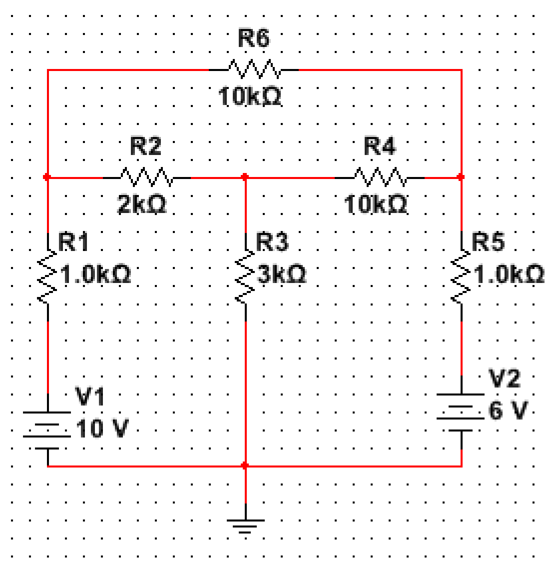
6.) The sources will automatically show up as 12V. We need to change this. Double click on the source and a menu will show up allowing you to change the voltage. Set the voltages to the correct values of 10V and 6V



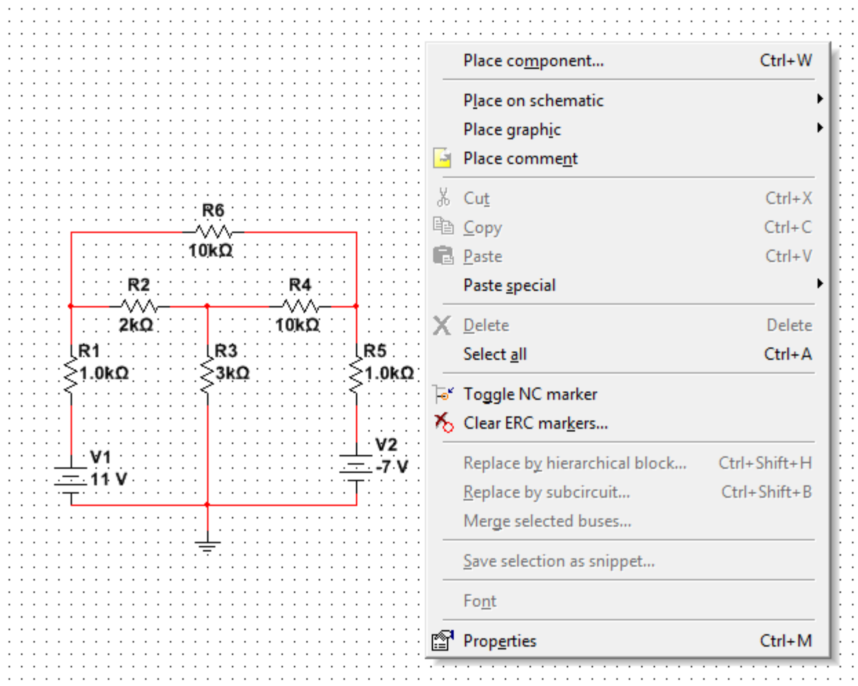
7.) We need to arrange out circuit elements. You can drag and drop the individual components. If you right click on a component you can rotate it by 90 degree.



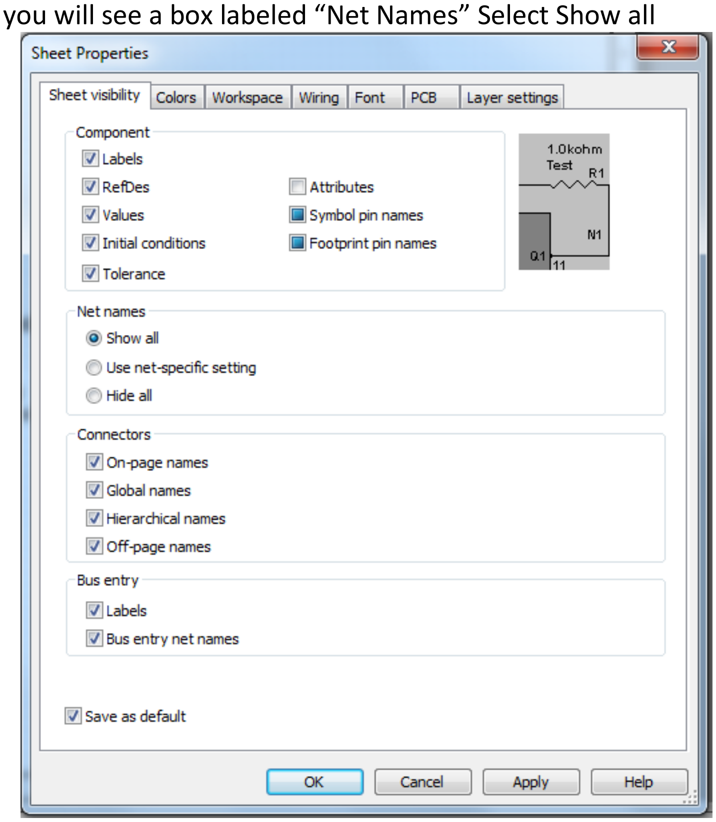
8.) Once we have our elements arranged we need to connect them. Hover the mouse over the end of one element and a dot will appear click and drag the connecting line to the element to connect it to. Double click on the element to connect it to and a wire will appear on your design.



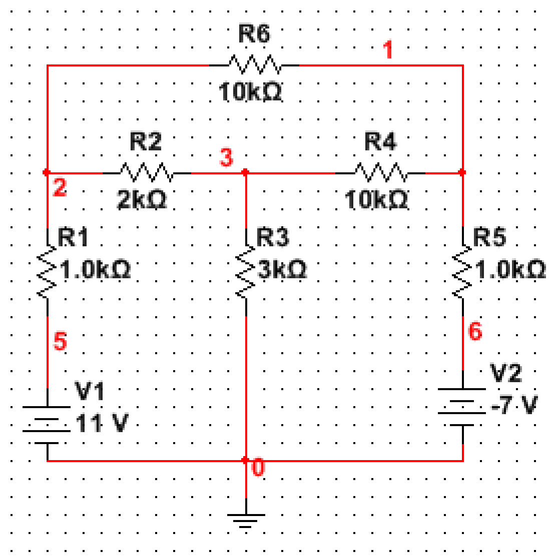
9.) We will want to display the names of the different branches of the circuit. Right click in the design window and select properties form the menu



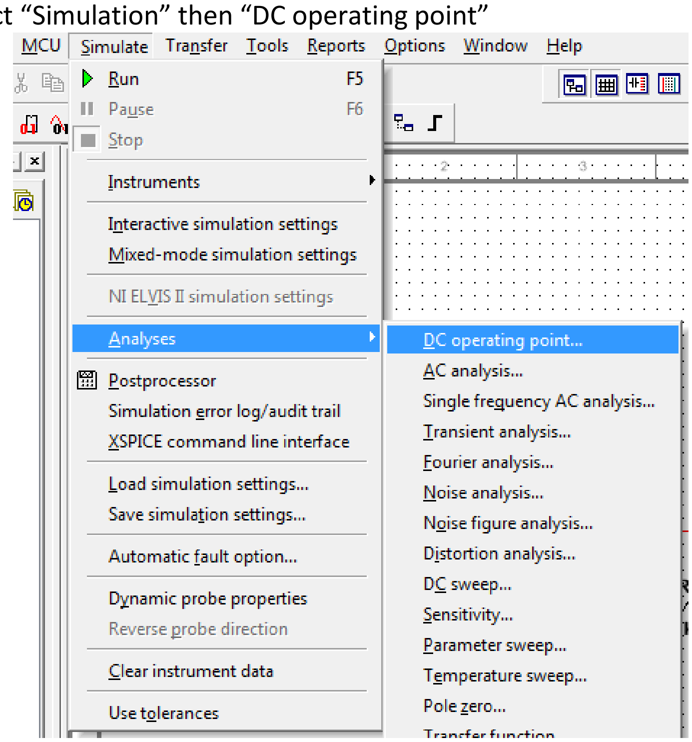
10.) In the center you will see a box labeled "Net Names" Select Show all



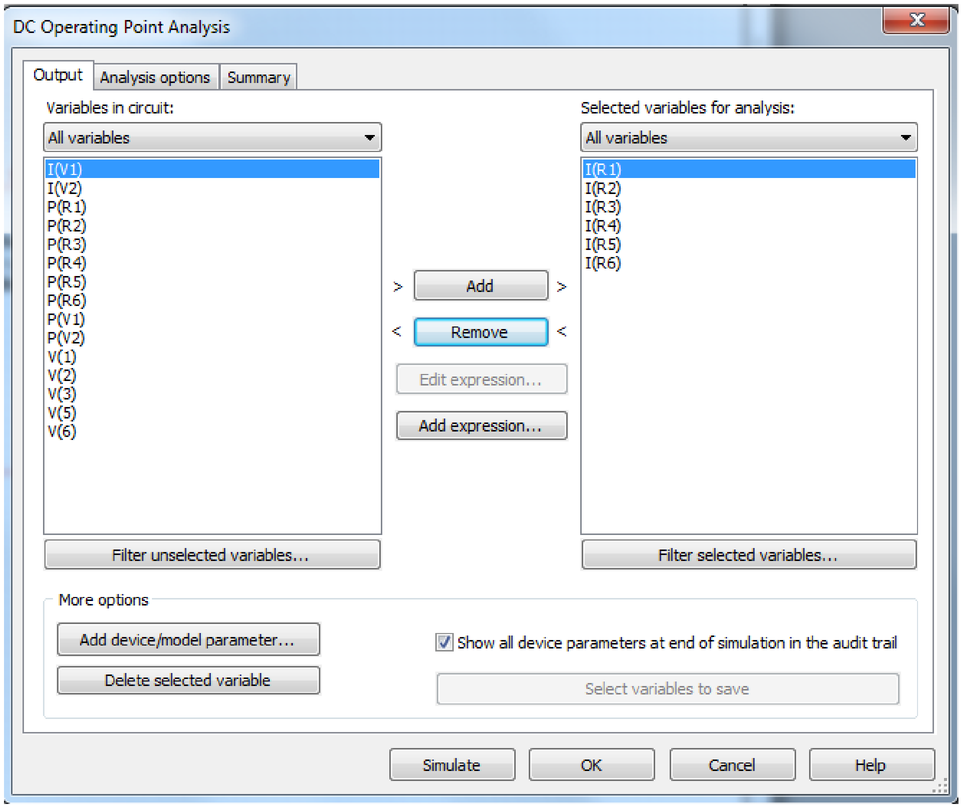
11.) Now the branches on your diagram will be shown with labels



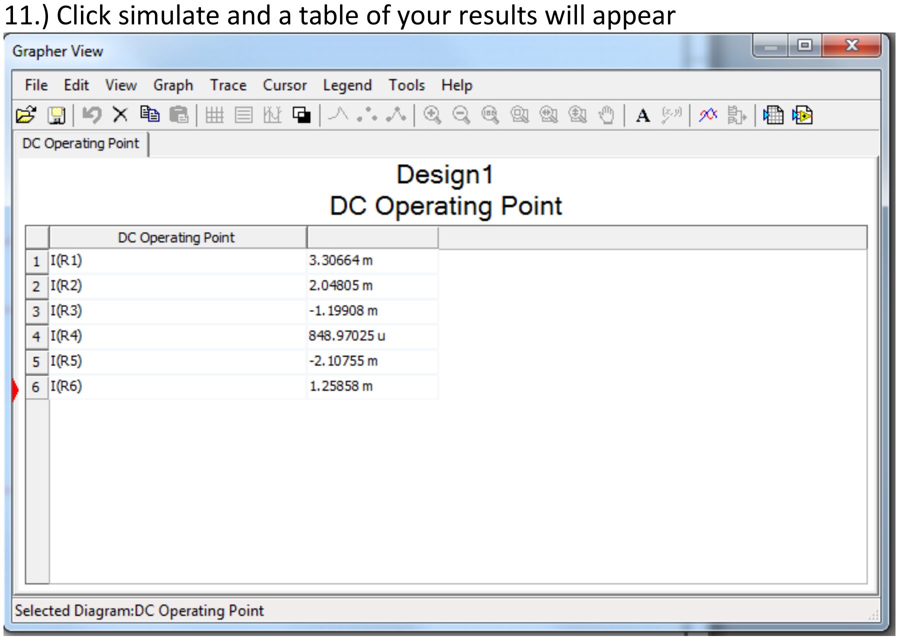
10.) Now we have designed dour circuit in multisim and we need to run our simulation. Form the menu bar select “Simulation” then “DC operating point”



10.) We want to find the current through and the voltage across each resistor. Select the current values shown as I(R1) etc. and Add them to the analysis summary



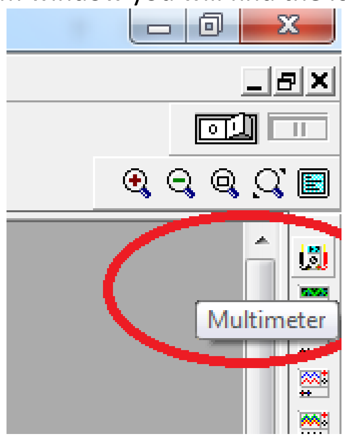
11.) Click simulate and a table of your results will appear



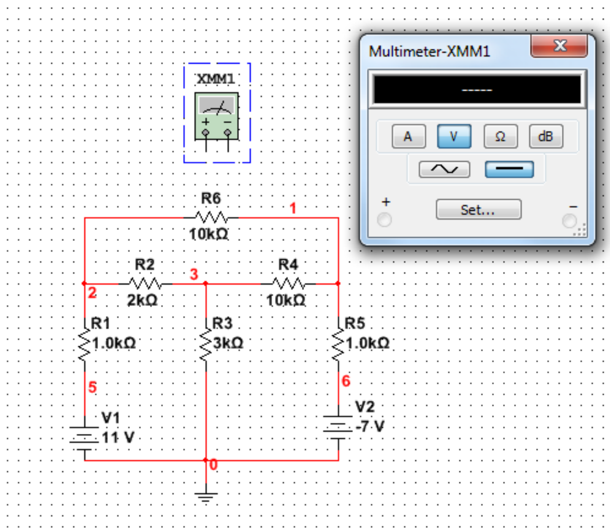
*****YOU WILL GET DIFFERENT VALUES FROM ONES SHOWN HERE. If you look closely you will see my simulation has the 6V source incorrect form hwo it is shown in the diagram.**

12.) We need to find the voltages. We have two options

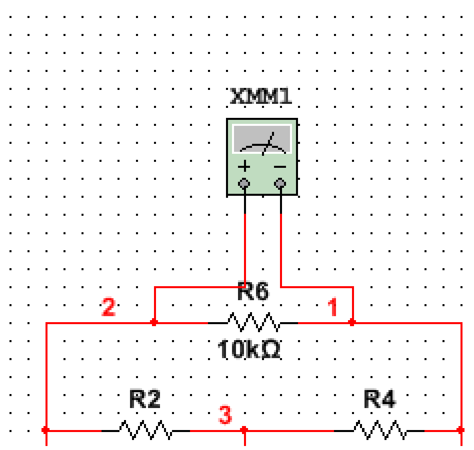
12a.) You can use the branch voltages in the Analysis.
12b.) You can use the multimeter tool.
13.) On the far right of the multisim window you will find the icon to add a multimeter



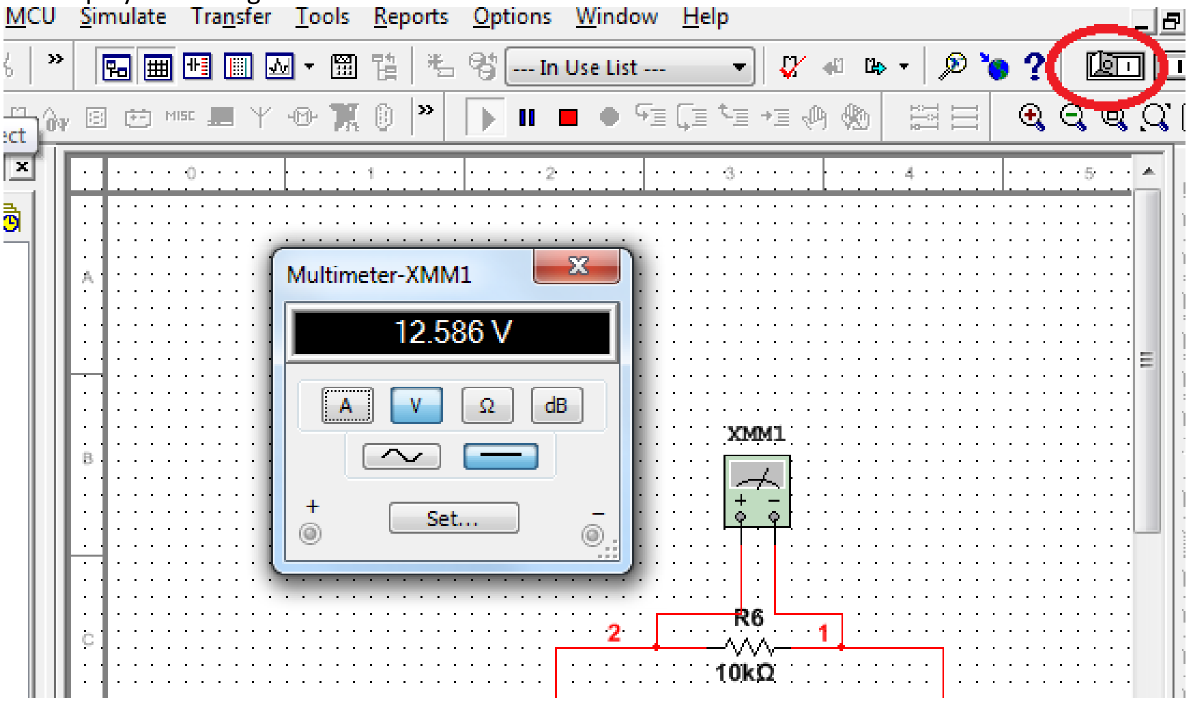
14.) Add it to the diagram



15.) Place leads from the meter across the resistor you want to measure



16.) Then click the simulate button at the top right of the window to the on position. The meter will display the voltage



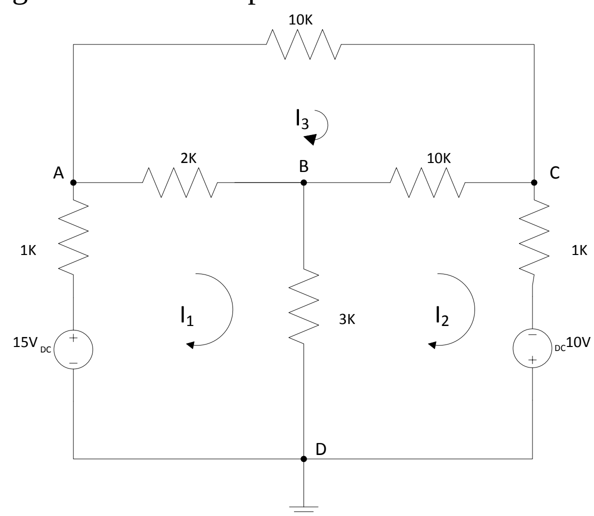
Appendix O Lab 6 Bench Instructions

Name: ____________________ Lab TA: ___________________

Date Performed: ____________________ Date Due: __________________

Lab Partner(s): ____

1.) Open LT Spice or Multisim on the lab computer. Construct the circuit shown below and run a simulation to find the values for potential and current through each resistor. Record the values. A guide for the LT Spice and Multisim can be found on pilot.



R	V	I
1K		
2K		
3K		
10K		
1K		
10K		

2.) Construct the circuit on a breadboard and measure the potential and current for each resistor.

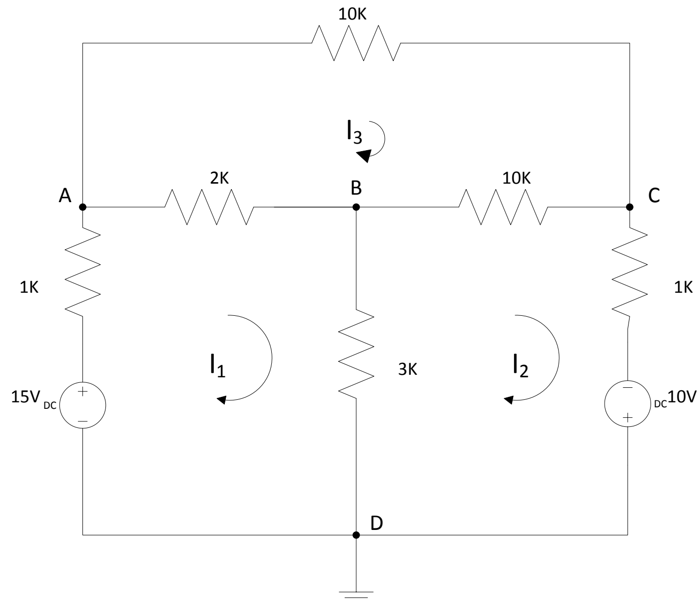
R	V	I
1K		
2K		
3K		
10K		
1K		
10K		

For Your lab report:

Build a table showing the values from your calculation, from LT Spice/Multisim, and your measured values. Find the percent difference between the calculated values and the measured, and between the LT Spice simulation and the measured values.

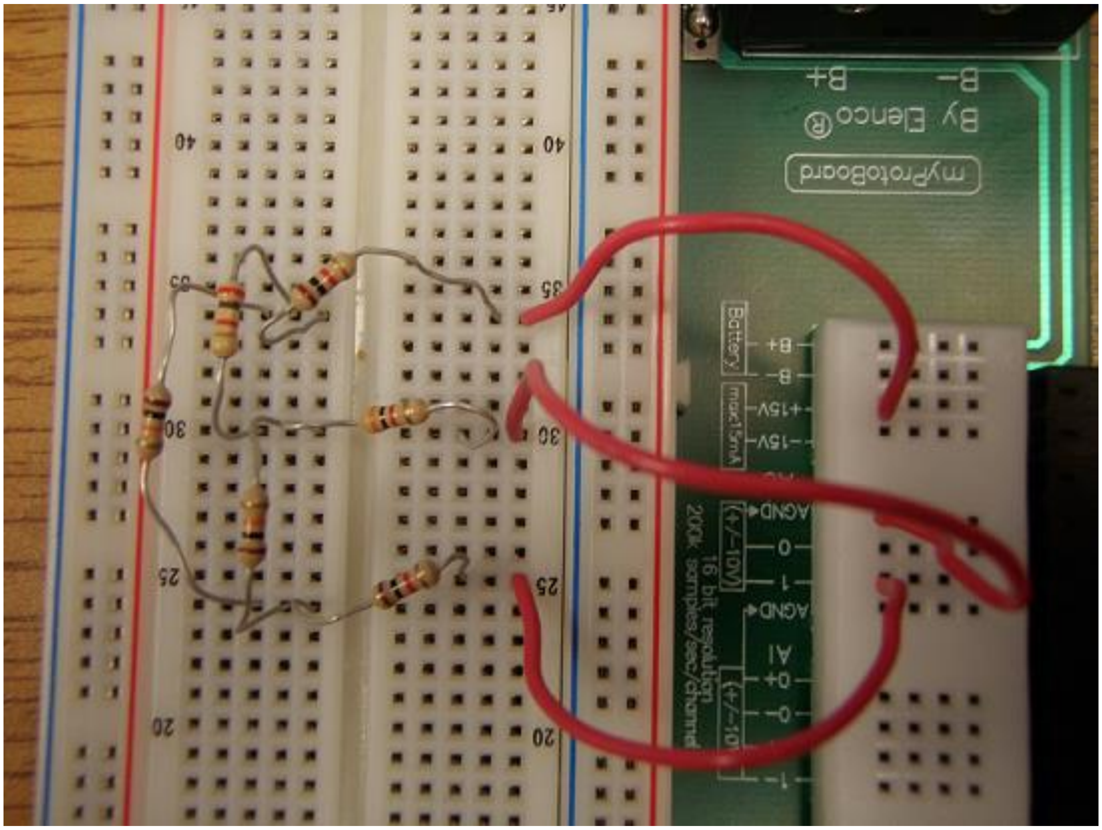
Appendix P Lab 6 myDAQ Instrcutions
Name: ______________________ Lab TA: _____________________
Date Performed: ______________________ Date Due: ____________________
Lab Partner(s): ____

1.) Open LT Spice or Multisim on the lab computer. Construct the circuit shown below and run a simulation to find the values for potential and current through each resistor. Record the values. A guide for the LT Spice and Multisim can be found on pilot. Pay careful attention to the direction of the 10V power supply.



R	V	I
1K		
2K		
3K		
10K		
1K		
10K		

2.) Construct the circuit on a breadboard and measure the potential and current for each resistor. We have multiple power supplies on the myDAQ so it is easy to construct a circuit with multiple sources. As ground is common for both we only need one ground on the protoboard. An example is shown below. NOTE your circuit will not be identical to the one shown below.



R	V	I
1K		
2K		
3K		
10K		
1K		
10K		

For Your lab report:
Build a table showing the values from your calculation, from LT Spice/Multisim, and your measured values. Find the percent difference between the calculated values and the measured, and between the LT Spice simulation and the measured values.

Appendix Q Lab 7 Instructions

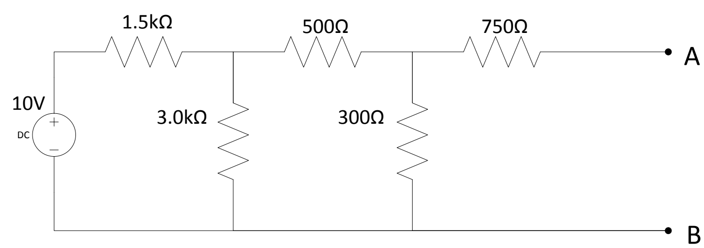
Name: ____________________ Lab Instructor: ___________________

Date Performed: ____________________ Date Due: __________________

Lab Partner(s): ____

The purpose of this laboratory is to practice the Thevènin and Norton circuit theory. Also, you will reinforce your previous understanding of voltage, current, and resistance measurements.

1. Build the circuit shown below



A. Use the voltmeter to measure the open-circuit voltage across terminals A and B.

B. Now, remove the 10.0 V source, and replace it with a short (ie a jumper wire between the 1.5K resistor and the 3.0K resistor, do not change any other parts of the circuit). Use the multimeter to measure the resistance across terminals A and B. This is your Thevènin resistance, R_{TH}.

C. Reconnect the source, short across terminals A and B, and measure the short circuit current. (The Norton current)

2. Find a resistor with a value as close as possible to the Thevènin Resistance you found in part 1. Find other resistors matching the values show in the table below. Place each resistor across the A B opening and measure the voltage across them. Calculate the power through each.

$R_L(\Omega)$	$V_L(v)$	$P_L(W)$
$R_L \approx (1/10)R_{TH}$=		
$R_L \approx (1/5)R_{TH}$=		
$R_L \approx (1/3)R_{TH}$=		
$R_L \approx (1/2)R_{TH}$=		
$R_L \approx R_{TH}$=		
$R_L \approx 2R_{TH}$=		
$R_L \approx 3R_{TH}$=		
$R_L \approx 5R_{TH}$=		
$R_L \approx 10R_{TH}$=		
$R_L \approx 100R_{TH}$=		

For your lab report

Include a table with your calculated and measured values for Thevènin Voltage, Thevènin Resistance, and Norton Current. Include a percent difference between calculated and measured values.

The table you created in part 2

Produce a graph of P_L on the Y axis and R_L in the X axis using your data from the lab. Include the graph in the Data section of the lab. The graph should be created in Excel, Matlab, or some such program. **IT SHOULD NOT BE HAND DRAWN**. Use the graph to determine the R_L for maximum power transfer. Compare this to your predicted value

Is the shape of your graph what you would expect? Explain why or why not?

Appendix R Lab 8 Bench Instructions
Name: ____________________ Lab TA: ___________________
Date Performed: ____________________ Date Due: __________________
Lab Partner(s): ____

The purpose of this laboratory is to learn about the oscilloscope, and introduce the ideas related to AC Signals.

Read the whole lab carefully before beginning lab.

You will need two coaxial cables with alligator clip leads at the end.

Setting Up Our Signal

1.) Turn on the computer. We will use the computer to generate our AC signal. Connect one cable to the output box connected to the computer. Use the top most terminal
2.) Open the function generator program: Programs>Velleman>PC2000se>function generator
3.) Select a smooth sine wave set the offset voltage to 5.0 V and the frequency to 1 kHz.
4.) Place a 1 kΩ resistor on the breadboard and connect it to the function generator. To do this set the breadboard up as normal, but instead of connecting the two wires to the power supply clip them to the function generator, red-to-red, and black-to-black

Setting Up The Oscilloscope

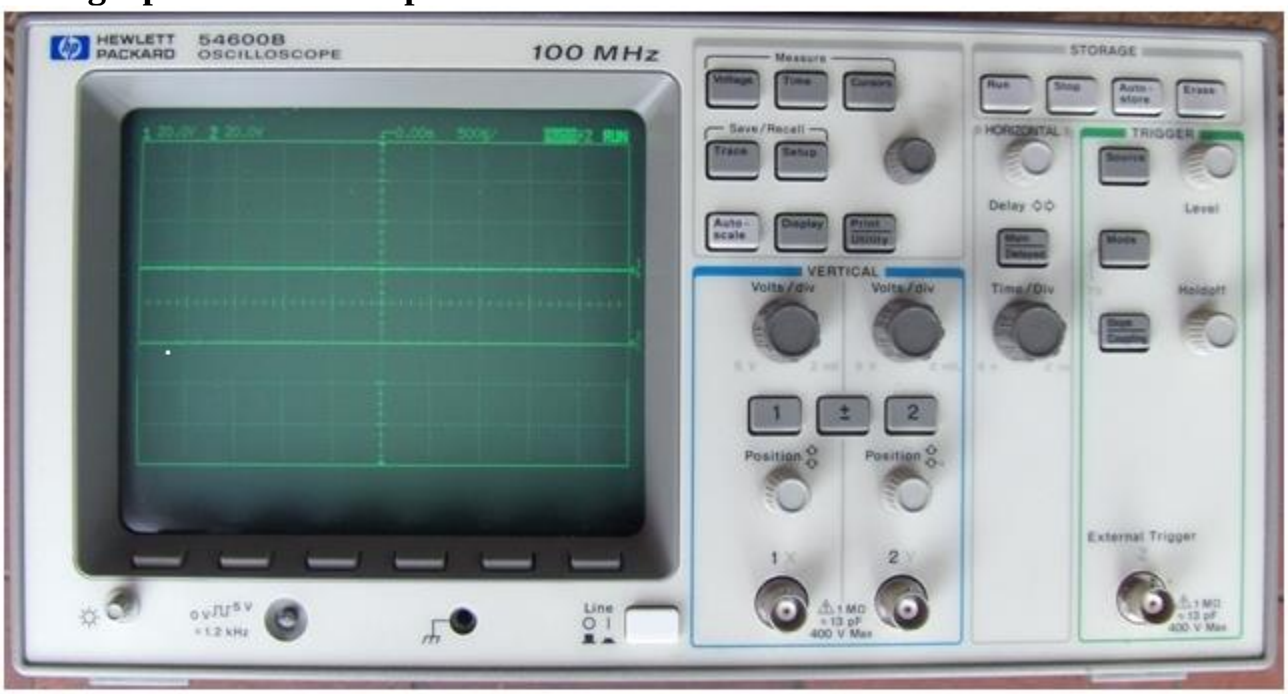


Figure 1 the oscilloscope

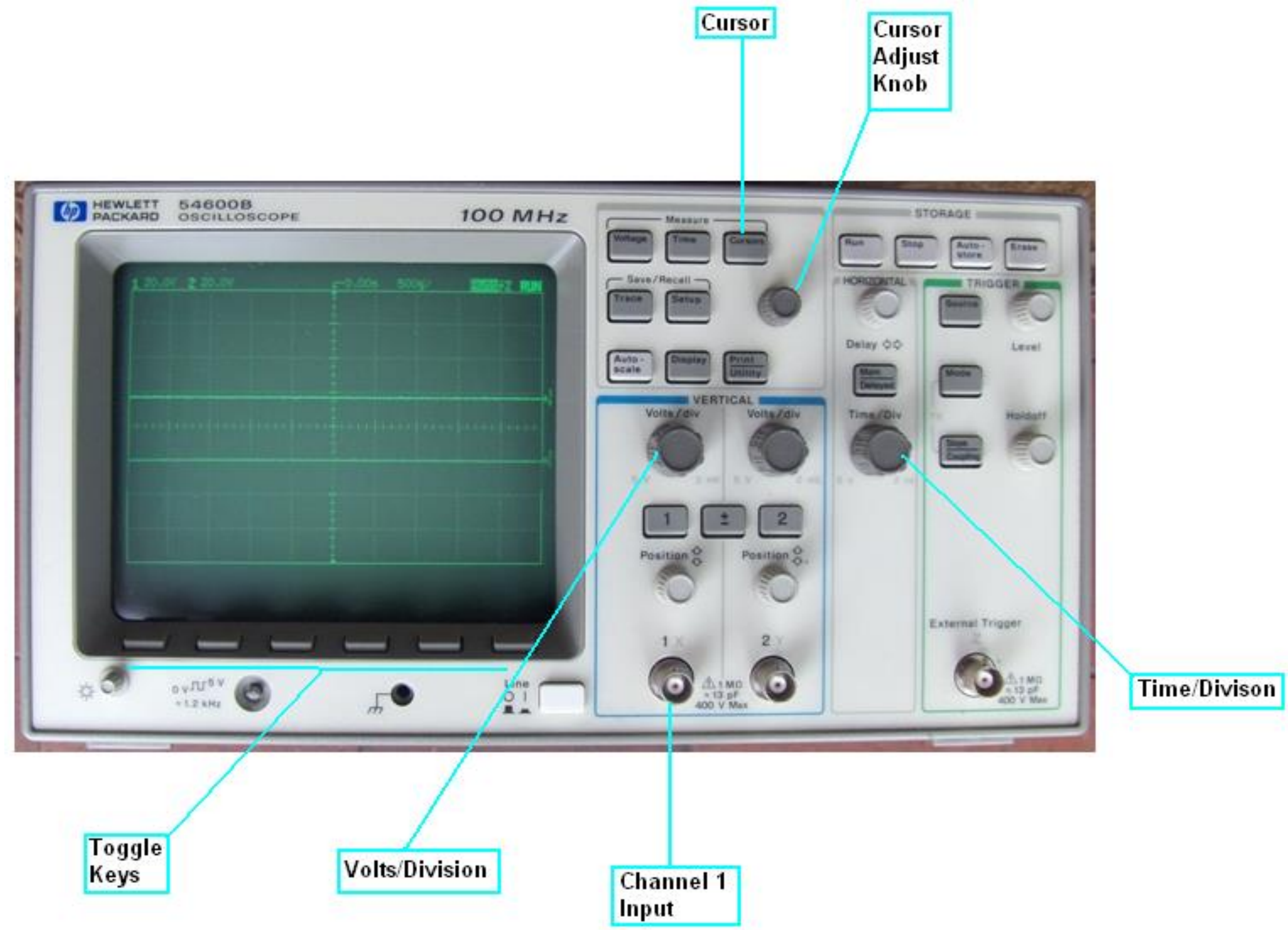


Figure 2 Detail of oscilliscope functions

1.) Connect the second cable to channel 1 of the oscilliscope. The oscilliscope screen displays voltage (or current) on the vertical and time on the horizontal. We can adjust the scale by using the volts/division knob and the time/division knobs. We will explore using both of these. Connect to leads to either side of the resistor.

2.) Select the Auto-Scale button. This will center and resize the signal to fit the screen.

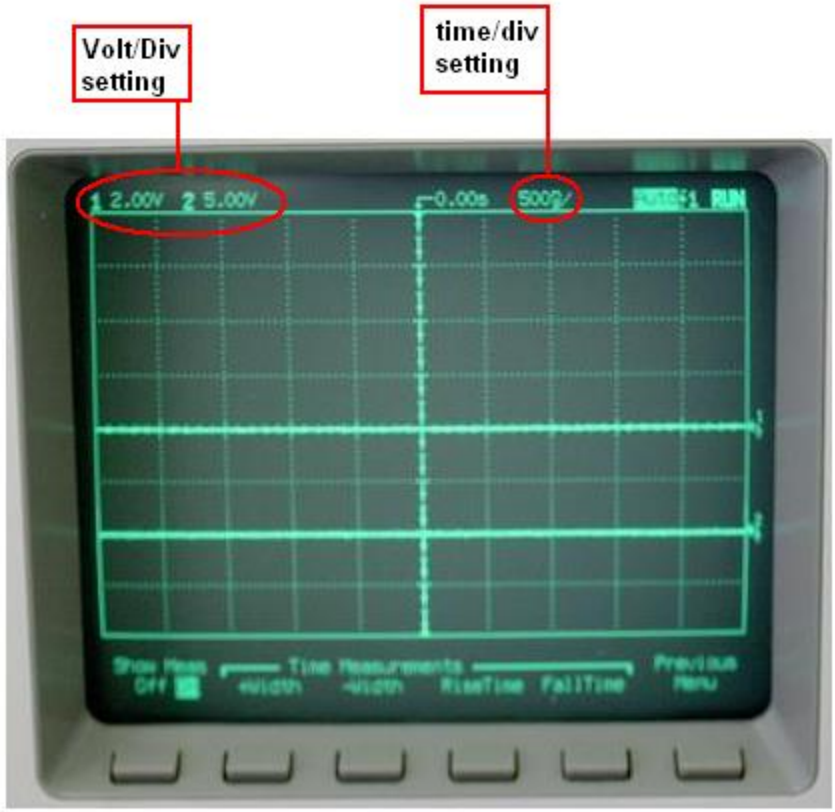


Figure 3 Oscilliscopre screen

Figure 2 oscilloscope screen. The 1 and 2 on the volt/div setting refers to channels 1 and 2 in this lab we only use channel 1

3.) What is the volts/div setting and the time/div setting after using auto scale?
4.) Adjust the time/division setting so only one cycle is displayed on the screen.
5.) What is the new time/division setting?

Volts/division means each whole vertical block represents that many volts. Time division means each horizontal block is that time value. In the picture above, channel 1 is 16V from top to bottom of the screen. 8 divisions x 2 volts/division = 16 volts

Calculate the V_p, V_{pp} and frequency of the measurements on screen.

6.) Hit the cursor button

The toggle buttons are just below the screen they allow us to go through various menus. The current function is shown at the bottom of the screen. See figure 2 above.

7.) Use the toggle buttons to select the cursor for time. Use the cursor to find the time for one complete cycle.
8.) Use the toggle buttons to select the cursor for volts. Use the cursor to find the V_p.
9.) Set the frequency to 2 kHz and repeats steps 2-9

For your Lab Report

Include a table of the values for V_p, V_{pp}, and frequency you found by using the time/div & volt/div settings and the cursors. Include a percent difference between the two.

Why is there a percent difference between the two methods of finding frequency and V_{pp}?

What happens to the signal if you make the time/div very small? Very big?

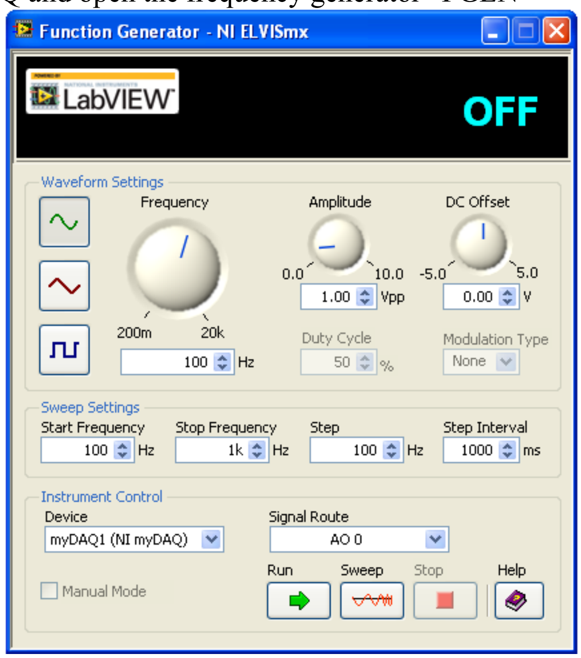
Appendix S Lab 8 myDAQ Instructions
Name: ____________________ Lab TA: ___________________
Date Performed: ____________________ Date Due: __________________
Lab Partner(s): ____

The purpose of this laboratory is to learn about the oscilloscope, and introduce the ideas related to AC Signals.

You will need two coaxial cables with alligator clip leads at the end.

Setting Up Our Signal

1.) Connect your myDAQ and open the frequency generator "FGEN"



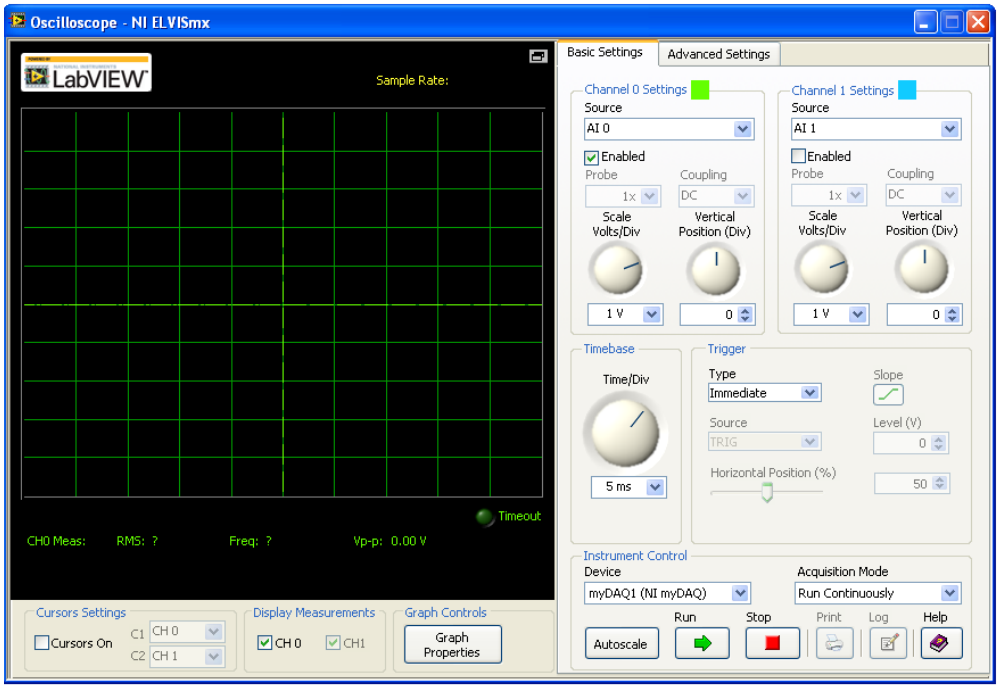
2.) Select a smooth sine wave, the green wave. Set the frequency to 1kHz and amplitude to 10.0V

3.) You can ignore the "Sweep Settings", we will not be using it. Make sure the Signal rout is set to AO 0. Based on this we will connect our jumper wires to AO 0 terminal 1 and AGRND, the same as we did for most of our DC set ups.

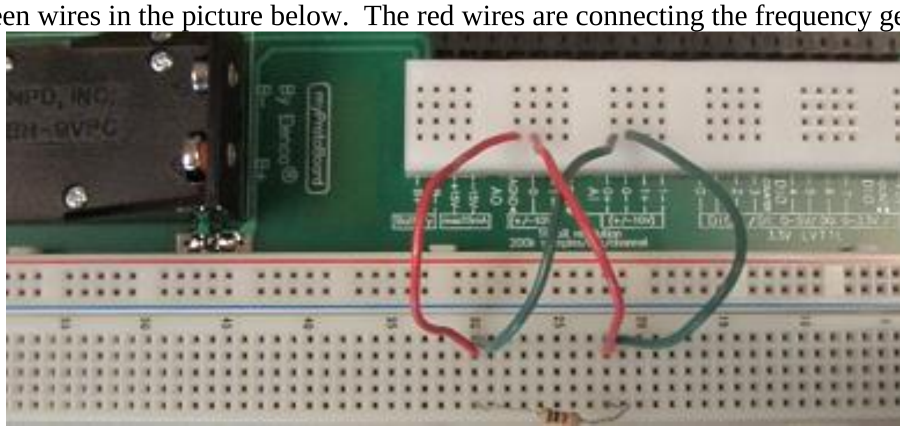
4.) Place a 1 kΩ resistor on the breadboard and connect it to the function generator. Click the run button

Setting Up The Oscilloscope

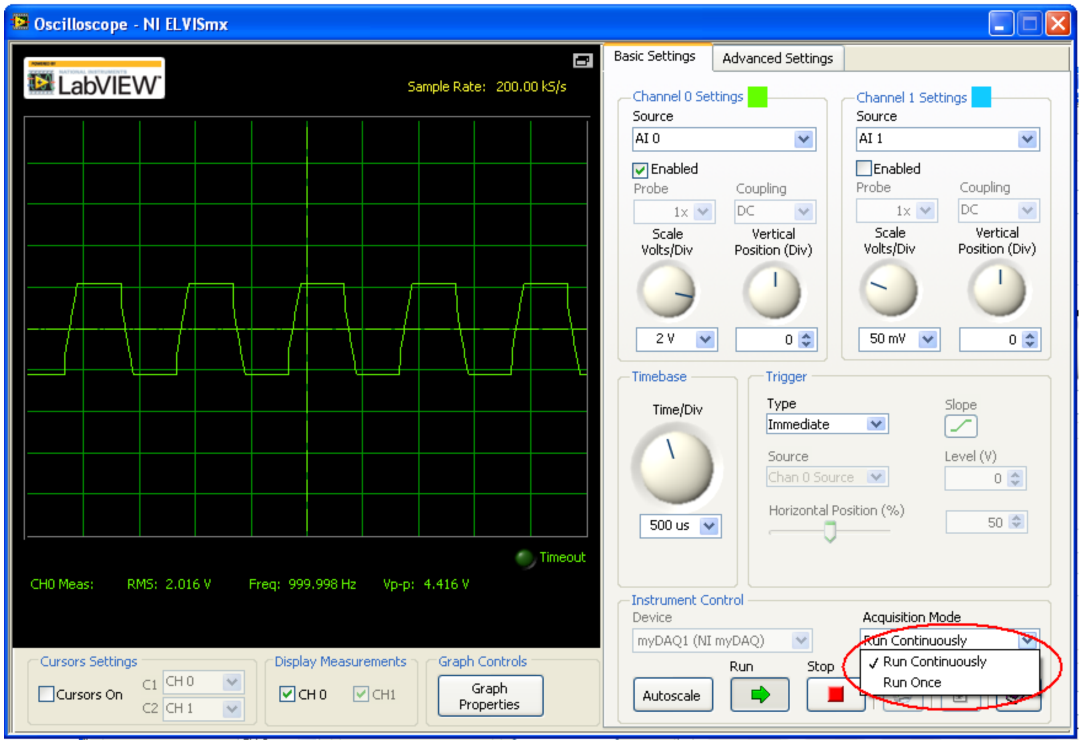
1.) Open the Oscilloscope "SCOPE" in the Instrument dashboard.



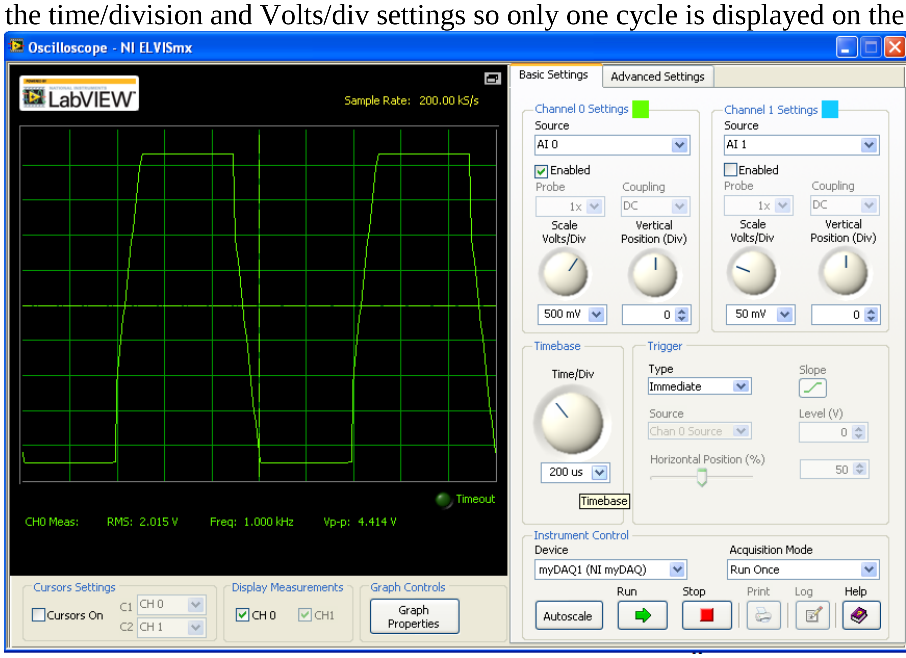
2.) The oscilloscope will measure directly off the protoboard. Select as the source AI 0. On the breadboard connect wires across the resistor leading to AI 0- and AI 0+ as shown below. These are the green wires in the picture below. The red wires are connecting the frequency generator



3.) The wave form on the screen will be moving, select autoscale. Under Acquisition mode select “Run Once”.

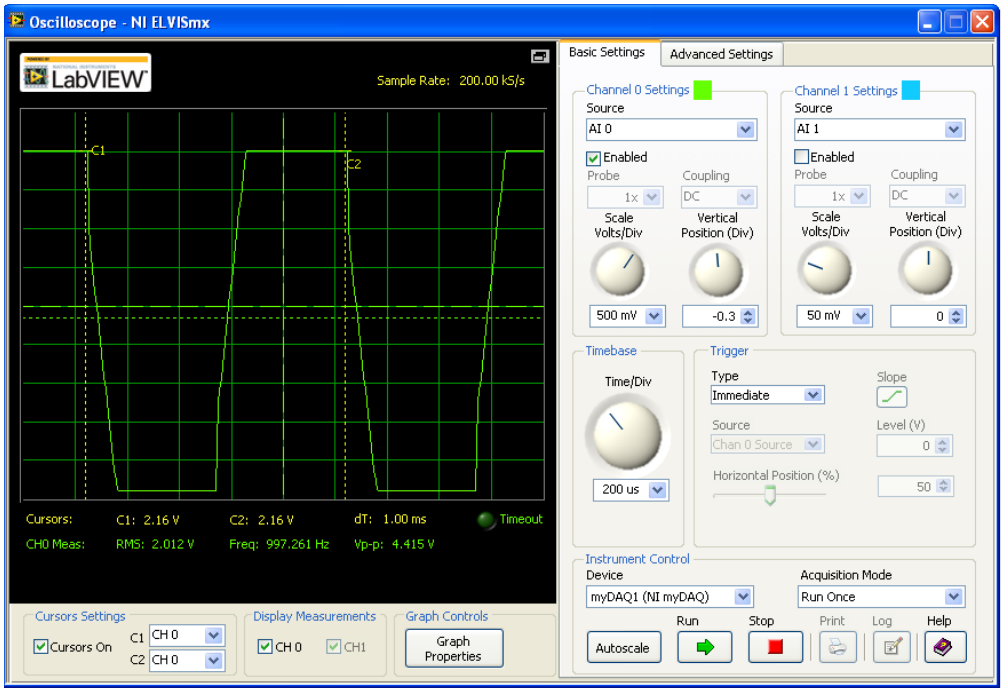


4.) Adjust the time/division and Volts/div settings so only one cycle is displayed on the screen.



The V_{pp} and frequency of the measurements are shown at the bottom of the screen.

5.) Check the "Cursors On" box. You will get two dashed yellow lines. Make sure that C1, cursor 1, and C2, cursor 2, are both set for CH 0. You can drag and drop these yellow lines. Drag the lines so they enclose on complete cycle. Notice as you drag the lines the values for C1 and C2 move along the graph and display the values. The value dT displayed on screen is the time for one cycle or Period.



6.) Move the cursors to find the V_{pp} and the frequency.
7.) Set the frequency to 2 kHz and repeats steps 2-6

For your Lab Report

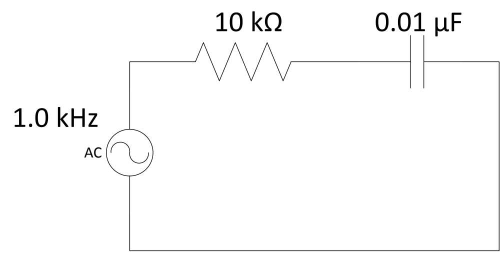
Include a table of the values for V_p, V_{pp}, and frequency you found by using the time/div & volt/div settings and the cursors. Include a percent difference between the two.
Why is there a percent difference between the two methods of finding frequency and V_{pp}?

What happens to the signal if you make the time/div very small? Very big?

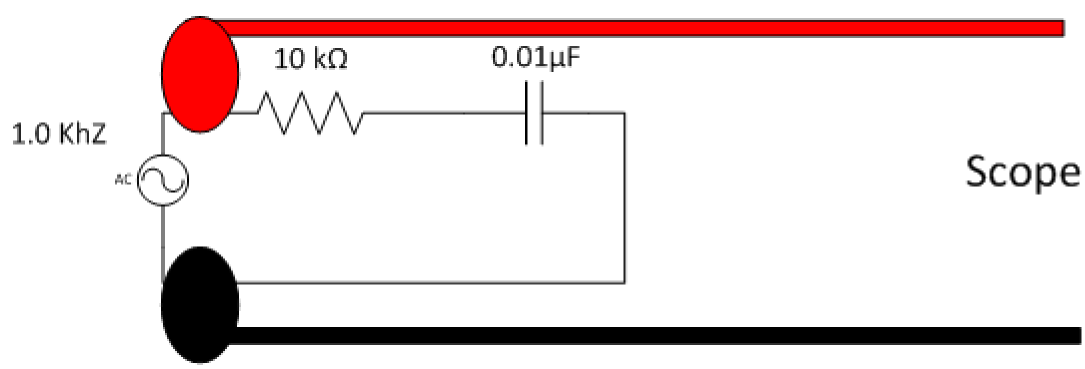
Appendix T Lab 9 Bench Instructions
Name: ____________________ Lab TA: ___________________
Date Performed: ____________________ Date Due: _________________

The purpose of this laboratory is to learn about **RC circuits, RL circuits, and time constants**. Also, you will reinforce your previous understanding of voltage, current, and resistance measurements.

Construct a circuit with a 10 kΩ resistor in series with a 0.01 μF capacitor. Make sure your resistor is the first element after the source. Open the Frequency generator and set it to a 5 V peak-to-peak, with a frequency of 1.0 kHz use a square wave signal.



We will measure the voltage across both the resistor and capacitor. When using the oscilloscope we have to connect the ground lead to the ground for the entire circuit. Observe the waveform



Measure the voltage across the Capacitor.

Use the Oscilloscope to find the time constant for the capacitor as it is charging.

Construct a circuit with a 5.1 kΩ resistor in series with a 0.01 μF Capacitor. Make sure your resistor is the first element after the source. Open the Frequency generator and set it to a 5 V peak-to-peak, with a frequency of 1.0 kHz use a square wave signal.

We will measure the voltage across both the resistor and capacitor. When using the oscilloscope we have to connect the ground lead to the ground for the entire circuit. Observe the waveform

Measure the voltage across the capacitor.

Use the Oscilloscope to find the time constant for the capacitor as it is charging.

For Your Lab Report

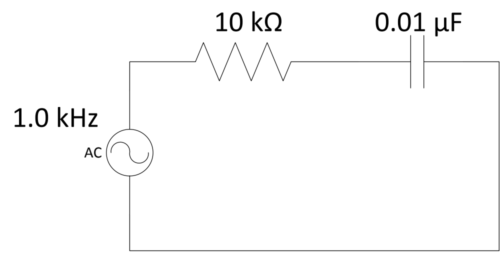
1.) Which would have a bigger impact upon the time constant, increasing the resistance or increasing the size of the capacitor? Explain your answer.

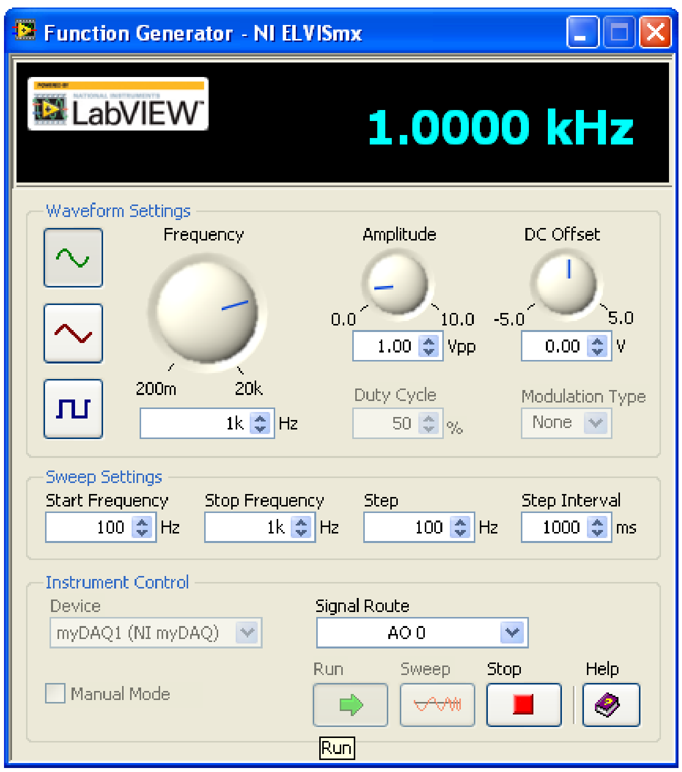
Construct a table with the measured time constants, the expected time constants and the percent difference between the two.

Appendix U Lab 9 myDAQ Instructions
Name: ______________________ Lab TA: ____________________
Date Performed: ______________________ Date Due: ____________________

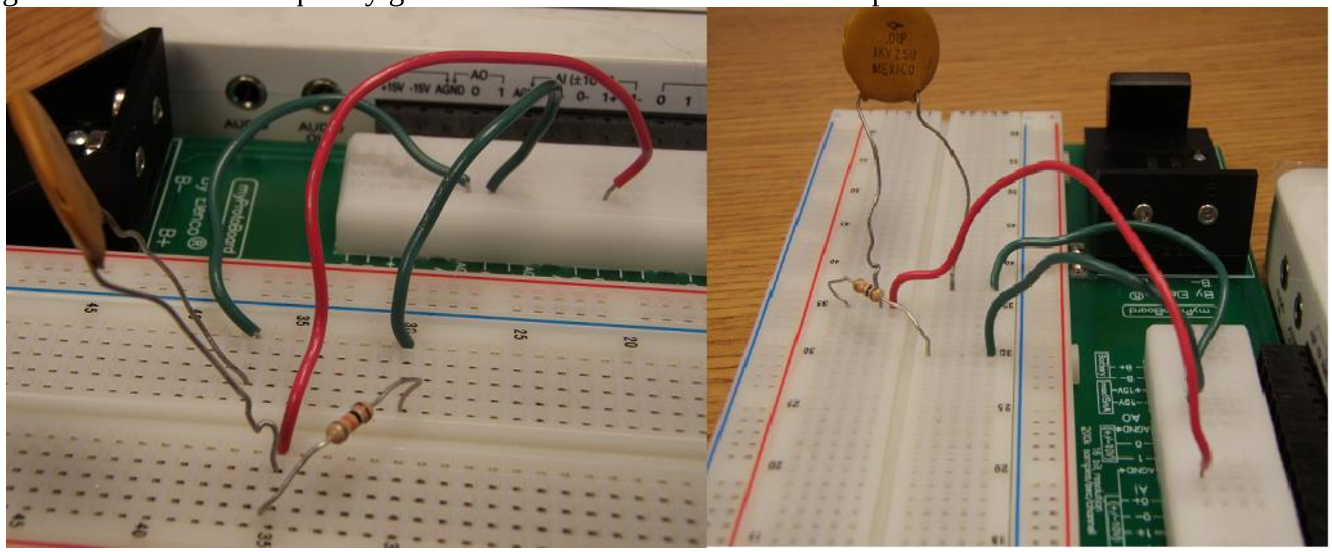
The purpose of this laboratory is to learn about **RC circuits and time constants**. Also, you will reinforce your previous understanding of voltage, current, and resistance measurements.

Construct a circuit with a 10 kΩ resistor in series with a 0.01 μF capacitor. Make sure your resistor is the first element after the source. Open the Frequency generator and set it to a 5 V peak-to-peak, with a frequency of 1.0 kHz use a square wave signal.

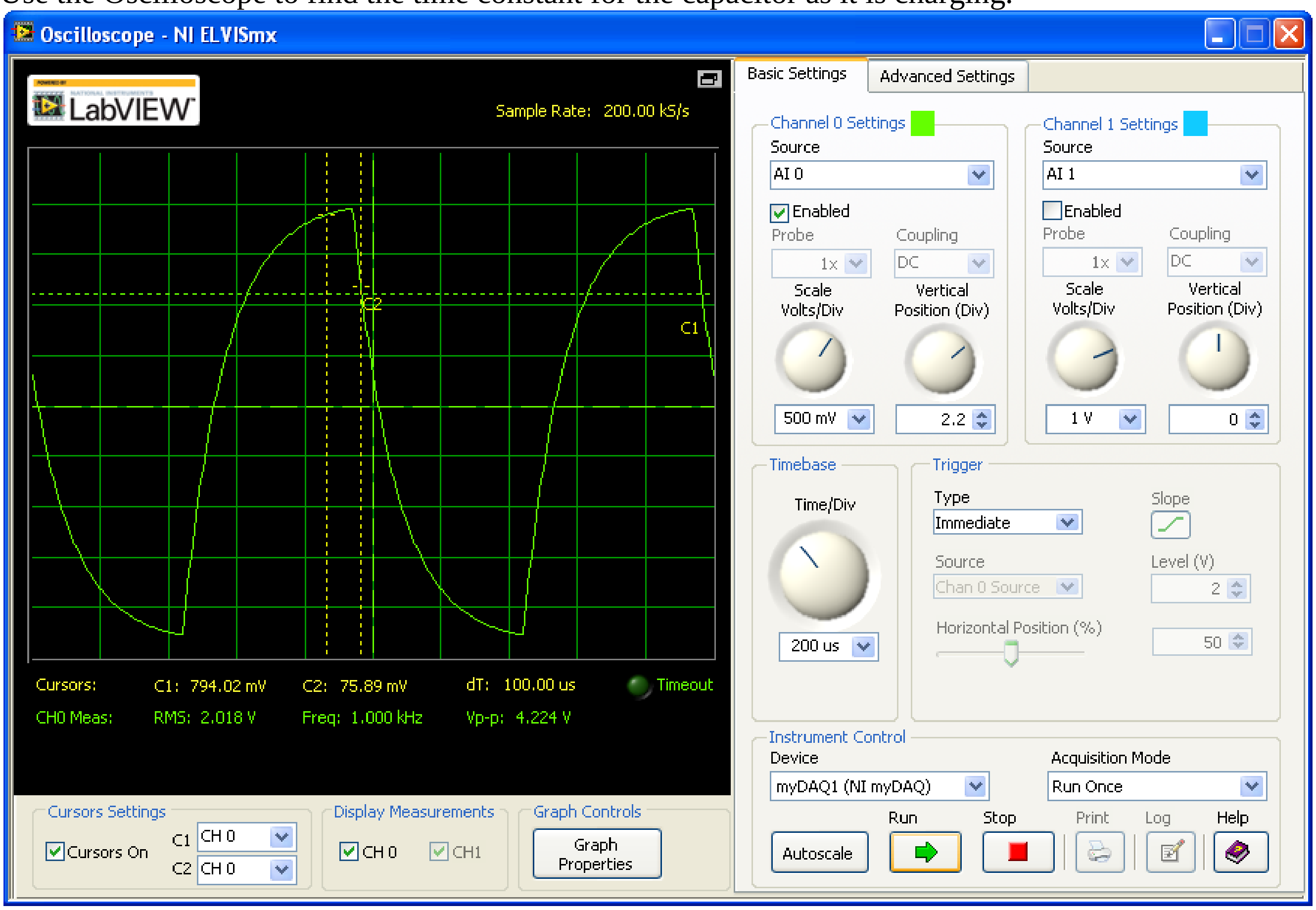




Measure the voltage across the Capacitor. The picture below show a sample circuit. The green wires are the frequency generator and the red is the oscilloscope.



Use the Oscilloscope to find the time constant for the capacitor as it is charging.



Construct a circuit with a 5.1 kΩ resistor in series with a 0.01 μF Capacitor. Make sure your resistor is the first element after the source. Open the Frequency generator and set it to a 5 V peak-to-peak, with a frequency of 1.0 kHz use a square wave signal.

Measure the voltage across the capacitor.

Use the Oscilloscope to find the time constant for the capacitor as it is charging.

Move the Oscilloscope connection so you can see the voltage across the resistor and capacitor.

For Your Lab Report

1.) Which would have a bigger impact upon the time constant, increasing the resistance or increasing the size of the capacitor? Explain your answer.

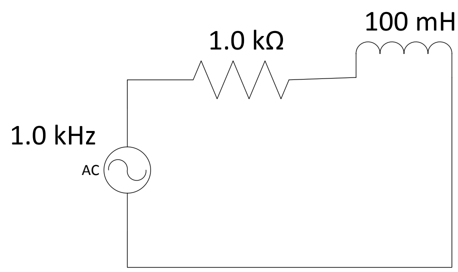
Construct a table with the measured time constants, the expected time constants and the percent difference between the two.

Appendix V Lab 10 Bench Instructions
Name: _____________________ Lab TA: ____________________
Date Performed: ____________________ Date Due: ____________________

The purpose of this laboratory is to learn about RL **circuits, RLC circuits, and time constants**. Also, you will reinforce your previous understanding of voltage, current, and resistance measurements.

RL Circuits

Construct a circuit with a 1.0 kΩ resistor in series with a 100.0 mH inductor. Make sure your resistor is the first element after the source. Open the Frequency generator and set it to a 5 V peak-to-peak, with a frequency of 1.0 kHz use a square wave signal.



We will measure the voltage across the inductor. When using the oscilloscope we have to connect the ground lead to the ground for the entire circuit. This is the same as we did for Lab 9 in an RC circuit. Observe the waveform; make a sketch of voltage across the inductor for reference when answering questions in your lab report. You will likely need to adjust the settings on the oscilloscope so as to make the waveform as large as possible

Measure the voltage across the inductor.

Use the Oscilloscope to find the time constant for the inductor as it is discharging.

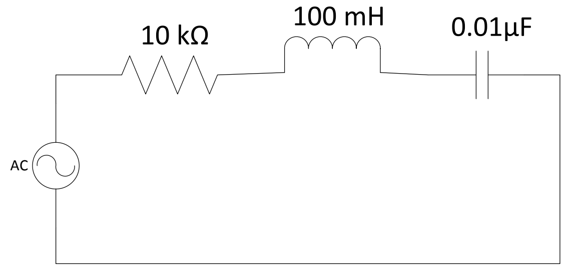
RLC Circuit

For an RLC circuit we can calculate the resonant frequency of the circuit. This si the frequency at which the impedance is at a minimum. We can calculate this frequency using

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

Calculate f_o for a circuit made with a 10 kΩ resistor, 100 mH inductor, and 0.01 μF capacitor in series.

Build the circuit shown below. Set the oscilloscope to measure the output across the inductor and capacitor



We will vary our frequency. For each frequency you will measure the peak-to-peak voltage

$f=0.1f_o$
$f=0.25f_o$
$f=0.5f_o$
$f=f_o$
$f=2f_o$
$f=3f_o$
$f=4f_o$

For Your Lab Report

1.) Explain why the voltage across the capacitor did not have the same pattern as the voltage across the inductor.

2.) Use Excel, Matlab, or some other software to create a graph of the peak to peak voltage versus the frequency for part two.

Construct a table with the measured time constants, the expected time constants and the percent difference between the two.

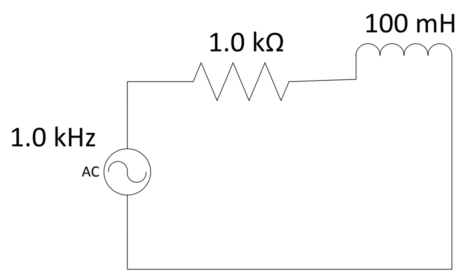
Construct a table showing all the frequency values used and the resulting peak to peak voltage for each frequency

Appendix W Lab 10 myDAQ Instructions
Name: ____________________ Lab TA: ___________________
Date Performed: ____________________ Date Due: __________________

The purpose of this laboratory is to learn about RL **circuits, RLC circuits, and time constants**. Also, you will reinforce your previous understanding of voltage, current, and resistance measurements.

RL Circuits

Construct a circuit with a 1.0 kΩ resistor in series with a 100.0 mH inductor. Make sure your resistor is the first element after the source. Open the Frequency generator and set it to a 5 V peak-to-peak, with a frequency of 1.0 kHz use a square wave signal.



We will measure the voltage across both the resistor and inductor. When using the oscilloscope we have to connect the ground lead to the ground for the entire circuit. This is the same as we did for Lab 9 in an RC circuit. Observe the waveform, make a sketch of both voltage across the resistor and across the inductor for reference when answering questions in your lab report.

Measure the voltage across the inductor.

Use the Oscilloscope to find the time constant for the inductor as it is discharging.

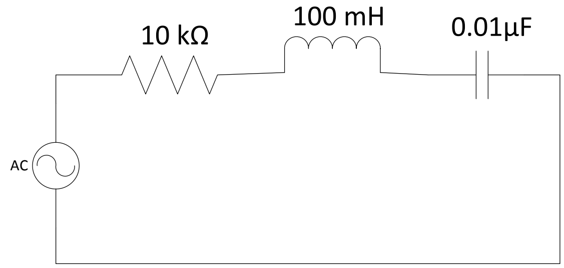
RLC Circuit

For an RLC circuit we can calculate the resonant frequency of the circuit. This si the frequency at which the impedance is at a minimum. We can calculate this frequency using

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

Calculate f_o for a circuit made with a 10 kΩ resistor, 100 mH inductor, and 0.01 μF capacitor

Build the circuit shown below



We will vary our frequency. For each frequency you will measure the peak-to-peak voltage

$f=0.1f_o$
$f=0.25f_o$
$f=0.5f_o$
$f=0.67f_o$
$f=f_o$
$f=1.5f_o$
$f=2f_o$
$f=2.5f_o$
$f=3f_o$

For Your Lab Report

1.) Explain why the voltage across the capacitor did not have the same pattern as the voltage across the inductor.

2.) Use Excel, Matlab, or some other software to create a graph of the peak to peak voltage versus the frequency for part two.

Construct a table with the measured time constants, the expected time constants and the percent difference between the two.

Construct a table showing all the frequency values used and the resulting peak to peak voltage for each frequency

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